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Thompson Ramo Wooldridge Inc.

CLEVELAND 17, OHIO

PROJECT

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ER-5048) OTS:

Final Report - Fabrication of a
60 Inch Diameter Stretch Formed
Aluminum Solar Concentrator

PREPARED BY:

Charles H Castle

C. H. Castle Sept 14, 1962
Project Engineer

CHECKED BY:

W. J. Leovic
Project Manager

APPROVED BY:

W. J. Skinner
Manager, Special Projects

See p. 1

DATE

September 14, 1962

DEPARTMENT

New Product Research

Thompson Ramo Wooldridge Inc.

CLEVELAND, OHIO, U. S. A.

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1.0 INTRODUCTION

The use of energy conversion devices with solar energy as the input source shows promise for use in space applications, particularly for extended periods of time and at higher power levels. Lightweight, efficient solar concentrating structures have received considerable analytical attention. The work described in this report extends the study of solar concentrators into one area of the fabrication feasibility phase. The work was accomplished on NASA Langley (NASA Contract NAS 7-154) over the period from 19 June 1962 to 14 September 1962. The study entailed the fabrication of three 60 inch diameter aluminum concentrators by the stretch forming process.

2.0 SUMMARY

Three collectors were delivered to NASA Langley for evaluation per the delivery schedule in Section 3.2.

By delivery of this report, the final requirements of the contract have been met.

Inspection of the collectors showed the following:

1. Surface errors were encountered during stretch forming and were traced to a subgrade die and formation of Luder's stretch marks.

2. Additional surface errors were encountered during assembly of the paraboloidal shell and were predominantly located at the sector joints.

3. The surface quality therefore is not as high as should be achieved for use in a high temperature conversion device such as the thermionic type. However, it is quite adequate for use with lower temperature conversion devices such as the Rankine and thermoelectric types.

4. The weight was measured at 0.58 lb/ft^2 of collector intercepted area, which meets the 0.5-0.8 lb/ft^2 design goal.

5. The S/N 2 collector is predicted to be the best optically and should be evaluated first.

6. The surface imperfections which prevent the collectors from meeting the desired use for thermionic conversion devices have been evaluated and are primarily due to a subgrade die. The use of the die was necessitated by a limitation in funds,

wherein three attempts were made at obtaining the desired quality. However, the main cause for not meeting the quality was not because it cannot be achieved, but because an improper choice of die fabrication methods was made. Such a die quality can be achieved, but with the additional expenditure not available to this study. Therefore, the decision to study the remainder of the fabrication aspects without the desired die quality was made.

7. Additional work should be conducted in the fabrication of aluminum stretch formed concentrators. With improved die quality and sector joint design and use of an aluminum alloy that does not exhibit stretch lines, it is expected that the performance requirements can be met. The aluminum structure is attractive because of the low specific weight compared to other materials of construction, and it is non-magnetic.

3.0 DISCUSSION

3.1 Design Specification

The collectors were fabricated for evaluation as to their possible use in space power conversion systems. Therefore, they would ultimately be required to pass environmental tests typical of launch and space conditions as well as meet specific performance requirements. Once a collector geometry is established, its performance is primarily a function of the surface quality, if orientation accuracy and surface reflectivity are ignored. If a collector could be built which would meet the most difficult heat converter requirements, it can then be used in any other energy converter application. The design goals for this contract were therefore set to meet the requirements of the thermionic conversion system because of the higher temperature operation. The contract Statement of Work is repeated here. "Three solar concentrators shall be fabricated with design goals as follows:

3.1.1 To be used with a 2000°K cavity absorber.

3.1.2 Sixty inch diameter and 60° rim angle.

3.1.3 Geometric concentration efficiency of 95% at an absorber cavity aperture diameter of 1.0 inch. (Gross area concentration ratio of 3600:1) This efficiency does not include reflection, shadow, absorber and misorientation losses.

3.1.4 Bonded aluminum construction with paraboloidal sections fabricated by the stretch forming process.

3.1.5 Specific weight of 0.5 to 0.8 pound per square foot of concentrator intercepted area.

3.1.6 A circular ring shall be attached at the outer portion of the paraboloidal shell to provide mounting and stiffening of the assembly.

3.1.7 A high quality reflective film shall be vacuum evaporated onto the reflective side and overcoated with silicon oxide for protection purposes. The reflectivity to the solar spectrum shall be 0.85 to 0.90.

3.1.8 Each concentrator shall be optically inspected over the entire area to determine surface quality."

It should be noted that the design objectives are primarily to establish feasibility of the stretch forming method as to whether it can provide the required optical performance and be lightweight. Although refined vibration, acceleration, shock and other analyses were not appropriate at this time, these aspects have been considered. These aspects have been studied in previous company sponsored programs. The membrane shell and stiffener ring concepts were a result of these studies. For this reason the collectors are preprototype in nature rather than breadboard.

3.2 Delivery Schedule

The contract called for delivery of the three collectors and final report as shown below. Also shown are the actual shipment dates.

Item	Required Shipment	Actual Shipment
S/N 1	12 weeks after receipt of contract	6 weeks after
S/N 2	13 weeks	10 weeks
S/N 3	14 weeks	13 weeks
Final Report	16 weeks	13 weeks

3.? Collector Configuration

The collector assembly is comprised of a single thickness (membrane) paraboloidal shell reinforced at the outside edge by a circular ring as shown in Figure 3.3-1. The shell is assembled from eight 45° sectors joined at the radial edges by an adhesive bonded lap strip. The circular ring is assembled to the back side of the shell. A three point mounting attachment on the circular ring per NASA Langley drawing LC 903404 is provided as shown in Figure 3.3-1.

The single thickness shell concept was chosen for several reasons. First, a high degree of rigidity to loading is inherent due to the curvature of the shell, which is not sectioned for stowage. Therefore, there is no need to provide a large section modulus to resist beam-type deflections. Besides, the mode of failure of the shell would be by buckling rather than by exceeding the elastic limit. Aluminum provides advantage over other materials such as steel, nickel, or copper because of the lower density. Figure 3.3-2 illustrates this, where thickness is obtained when the equivalent pressure is less than the critical pressure. Note the resulting specific weights for the metals chosen. This analysis assumes equal externally applied pressure as equivalent to inertia loads due to a shock load of 100 g's. A thickness for aluminum was chosen to be .016 inch, although the cross-over point occurs at .011 inch. But this allows a reasonable factor of safety for this first sizing of a collector.

Secondly, the single thickness shell will have improved surface quality because there is no need for reinforcing structure on the rear face such as honeycomb or the various modifications thereof. To meet the same per-square-foot-weight, a thinner reflective face would be necessary where core mark-off would be even more pronounced.

Third, the single thickness shell provides a minimum heat barrier from the front to back faces, and thermal gradients will be minimized as to their distortion effect on optical performance.

Placement of the ring at the outer diameter introduces the stiffening necessary to transfer the uniformly applied launch loads to the support points (three in this case). It should be pointed out that the ring designed for this contract is probably not optimum in either weight or stiffness. However, it serves as an adequate item for the purpose of this study contract. There are two approaches to the design of the stiffener ring depending on a more thorough study of the temperature histories at various locations on the shell and ring as sun-to-shade cycling occurs. Figure 3.3-3 shows concept A where the ring is attached directly to the shell. Concept B introduces a cylindrical skirt between the actual stiffening section and the shell. The later concept is expected to allow larger thermal gradients before shell distortion is appreciable. For this contract, concept B was used because the tolerances on ring roundness and flatness are much less, and funds did not allow an expensive ring fabrication. Whether thermal or packaging requirements dictate the use of concept A shall be considered when it is shown that this method of fabrication will meet performance requirements.

An additional advantage in the use of aluminum alloy for construction is its non-magnetic properties. Equipment or instruments which are part of the payload and are sensitive to magnetic materials will not be influenced by the relatively large area of the aluminum collector.

3.4 Sector Forming

The 45° sectors used in the shell assembly are formed by the stretch forming process. The stock is pulled over the die in tension as in Figure 3.4-1. To achieve the shape, the stock is stretched beyond its yield point, where it enters the plastic range and retains the formed shaped with negligible springback. Figure 3.4-2 shows the stretch forming machine. Figure 3.4-3 shows stress strain curves for some 5052-0 aluminum alloy test specimens from the same lot as used in forming the sectors. Note that the average elongation down the center of the sheet was 2.8 percent and along the edge was 0.8 percent. It is suspected, however, that the elongation between the die edge and the jaws was greater than these values because of friction between the stock and die. In some of the earlier stretches, fractures occurred at the die edge in the vicinity of line X-X and also at the jaws in the vicinity of line Y-Y. However, once the correct stock length, initial jaw setting and final jaw setting were established, stock fracture was rare. The forming action took 1.5 seconds so that strain rates were .042 in/in/sec.

When the jaw tension was removed, there was little indication of springback since no voids could be detected visually or audially by finger tapping the stock. The process has good forming qualities. Even dirt, hair or die defects are faithfully reproduced when encountered.

The 5052-0 aluminum alloy was chosen for two reasons. First, it is a work hardening alloy rather than heat treatable and therefore is less susceptible to age hardening and any possible surface shape changes. Second, it is one of the alloys that can be supplied with a surface finish less than 2 microinches RMS and in large widths. The thickness was specified as .016 inch.

The die was fabricated from the back surface of a glass searchlight mirror and is composed of a reinforced epoxy outer surface with an under structure made of wood and reinforced plaster. To form a male die from the male master an intermediate female pattern was made. Despite three attempts at making the die, the final surface was not an exact reproduction of the master. This does not mean an exact replica cannot be obtained. The vendor chose to make the female of "Hydrocal" plaster and, especially on the first two, used hand touch-up techniques. Inspection of the third attempt showed a vast improvement over the first and second, although some defects were still noted. However, the limitation of funds forced acceptance of the third attempt. The effect of die defects will be discussed in the section on inspection.

To avoid die defects in future forming, one of three alternatives can be made:

1. Form over the glass master.
2. Fabricate from the glass master an epoxy female and an epoxy die, without any surface touching-up.
3. Fabricate a spin casting and cast an epoxy die from it.

The first or second choice would be used to build additional collectors of the geometry used in this contract. For other geometries, the third choice would be used since spin casting produces highly accurate paraboloidal surfaces.

During the forming process, it was noted that Luder's stretch lines were forming and causing surface distortions greater than the surface improvement process can cover. This was an unexpected result since these lines are seldom encountered in such a pronounced manner in other metals. They were not apparent when 31_ stainless steel was stretched over the same die. However, a general dulling of the surface lustre was noted in the 316 stretching. In this case the plastic deformation was probably occurring by very fine laminae slippage which did not cause pronounced Luder's lines. The surface improvement process can be applied with success, therefore.

The specimens recorded on Figure 3.4-2 were tensile tested to determine whether the Luder's lines were aggravated by the compound curvature being formed or whether elongation into the far plastic region had a bearing. The flat specimens did form Luder's lines comparable to those during forming and occurred early in the plastic region as shown. However, the rate of strain application did have a bearing. The faster strain rates produced finer Luder's lines. But the strain rate in the stretch forming exceeded the tensile test rates by at least 10 to 1. Therefore, it was concluded that there was no effect due to the compound curvature that the lines formed despite the location in the plastic region and there was no need to increase the rate of strain application.

The next step was to determine the degree of Luder's line formation from one alloy to another. It was found that the 5052 is one of the most susceptible to line formation and that the 3003 alloy, or particularly the 3004 alloy, has a marked reduction in strain mark severity. There is also a reported reduction in lines when stretching a 1/4 or 1/2 hard alloy instead of the soft condition. However, the reduced elongation property and small spread between the yield and ultimate limits will make these tempers harder to control in forming, if not preclude their use altogether for this particular shape.

During forming it was found necessary to protect the stock from being scratched by the die surface. Unprotected sheets showed considerable surface scratching which could not easily be covered by the surface improvement process. Several methods of introducing a buffer material were tried with varying success.

1. Mystic brand "Protecto Mask" tape was applied to the stock. This is a low adhesion type tape which was applied in single widths.

2. A sheet of polyethelene or PVA (poly vinyl alcohol) about .005" thick was attached to the stock by taping along the edges.

3. A sheet of PVA was stretched over and taped to the die.

4. A commercial die wax often used in stretch forming to eliminate or minimize scratching was applied to the die surface.

The use of plastic sheets or die wax applied over the die surface were the most successful in eliminating scratches. Application of the Mystic tape or plastic sheets to the stock eliminated scratching, but they took more time and effort to apply and to remove them. A difficulty encountered in the use of all these buffer methods was that any imperfections in the sheets or wax marked off on the formed stock. In all cases imperfections were noted. The least amount of mark-off was noted with use of die wax. Although,non-uniform thicknesses of wax during application to the die surface showed up as less detectable surface deviations because they covered larger areas. Additional work must be done in obtaining better plastic sheets or in uniform application of die wax.

In general, the distortions encountered must be eliminated. However, the formed sheets used for all three collectors were made in one production run. A total of 33 parts were stretched. Because of fund limitations, a second run with the additional cost of stock purchase, die set-up and forming could not be made. To truly evaluate the stretch forming process, it will be necessary to obtain a better die, purchase new alloy stock, obtain an adequate buffer sheet and make a second production run.

3.5 Sector Trimming

The sectors were trimmed from the stretch formed stock as shown in Figure 3.5-1. A high speed, rotary slotting saw was used to avoid edge distortions resulting from the usual tin snip or aircraft "nibbler" tools. The stretch formed stock was placed on the glass master with 1/4" thick plexiglass strips between the stock and master so as to prevent master damage. Rails were used to guide the saw when cutting along the radial edges. When cutting along the outside diameter, the saw was attached to a rotating beam centered at the vertex of the master. After sawing, the sectors were deburred without difficulty with a file. The trimming operation was quite successful. Only an occasional distortion was encountered when the slotting saw would stop. A slightly larger air motor should eliminate this. In most cases there was little if any additional file trimming required when the sectors were assembled together on the master.

The area on the back side of the sectors where adhesive was to be applied was roughened with emery paper to provide tooth for good shear strength in the bond. However, part way through fabrication of S/N 2 it was noted that this caused stress relief on the surface layer and a resulting surface distortion. The procedure was discontinued and the areas are now merely cleaned with solvents prior to bonding.

3.6 Surface Finish Improvement

In order to approach a mirror-like surface finish, it has been found that aluminum alloy sheets cannot be used as received. This applies to stock before or after stretch forming, and should not be confused with the Luder's lines discussed in the section on forming. The method used to improve the surface finish is to apply a "lacquer" type coating which results in a vast improvement in finish and can be classed as mirror like. Figure 3.6-1 shows a before and after comparison.

To ensure that the resulting layer is space worthy, the coating material should be a 100 percent solids polymer when cured out. The thinned epoxy types appear to be well suited for the application. In this case, the thinner is volatile and is used only to assure a low viscosity liquid to provide a smoother surface finish. The majority of thinner evaporates in a matter of minutes and is completely driven off during the cure cycle at elevated temperature.

The sectors were cleaned prior to application of the surface improvement layer as in Figure 3.10-10.

The coats can be applied by either spraying or dipping. To date, the dipping technique has been more successful, although there are some advantages to spraying. In both cases, the process has not been refined to the point where the cured coats are adequate. Two difficulties have been encountered; particles of dirt are noted on the surface and there are occasions when very minute "bubbles" are noted which reduce the reflectivity of the subsequent vacuum evaporated aluminum film. The particles can be eliminated by proper clean room procedures not available to this process because of fund limitation.

The "bubbles" are quite small (around .001") and it has not been determined whether they are air, water vapor, thinner or even coagulations of epoxy and catalyst. Some samples have been coated which are free of "bubbles" and others treated apparently in the same manner are covered with them. Again, a lack of funds has prevented the investigation that the "bubble" problem warrants, and it appears to be only marginal in nature. The thinner composition, cure history and humidity are suspects at this time, in that descending order of importance.

Coats applied by dipping measure from .0001" to .0005" thick, depending on whether the measurement is taken from the top or the bottom, relative to the way the sectors are placed to drain off excess liquid.

The S/N 1 collector was spray coated with "Relac", a commercially available surface finisher, because the thinned epoxy techniques were not quite adequate at the time. This product does not cure out to a 100 percent solids polymer because acetone and toluol attack the film, whereas the thinned epoxy films are resistant to these solvents. The S/N 2 collector was dip coated with thinned epoxy because previously coated samples were adequate. However, four of the sectors showed "bubble" patterns whereas the other four were much superior. The eight sectors were coated in the same batch, although the poorer ones were coated last, which indicates a cure-history quality control requirement.

The sectors were individually coated and subsequently reflective and protective film coated individually. This method was chosen, over the more desirable application of the three coats onto a complete collector, primarily because the processes were not developed enough to allow confidence that a complete collector would not be scraped. Ultimately, it will be desirable to apply coats on the complete assembly once process control is achieved.

3.7 Reflective Coating

The reflectivity of the sectors was increased by vacuum evaporation of 99.99 per cent pure aluminum over the surface improvement coating. Prior to evaporation of the aluminum, the sectors were cleaned by ion particle "glow" discharge and then coated with a layer of silicon oxide by vacuum evaporation. All three sequences were accomplished without breaking vacuum. However, the tank pressure and sequence durations were different as shown in Figure 3.10-10. The resulting coating thicknesses are also shown.

There was no cleaning performed on the sectors between the surface improvement process and the reflective coating process other than the discharge sequence while in the vacuum tank.

3.8 Protective Coating

To protect the aluminum coating against handling as well as degradation if exposed to higher temperatures, a coat of silicon oxide was vacuum evaporated over the aluminum. The thicknesses are shown in Figure 3.10-10 and were applied without breaking vacuum following the aluminum evaporation.

If it is necessary to clean the collectors due to dust or fingerprint accumulation the surface can be gently scrubbed with a lint free cloth and a 2 percent solution of Aerosol OT in water. Rinse with warm water, preferably distilled, to avoid water stains. The silicon oxide layer can be scratched if pressure is hard enough, however.

The Sunflower vacuum tank was used to apply the reflective and protective films.

3.9 Shell and Ring Assembly

The same glass searchlight mirror used to fabricate the stretch forming die was used to assemble the shell. Figure 3.9-1 shows the assembly in process. It was necessary to take care while placing the sectors in place to avoid scratching the silicon oxide protective layer.

When the sectors were in place, the areas of bonding were cleaned with solvents to assure good adhesion of the bond. One inch strips of .016" aluminum alloy, obtained from the excess stock trimmed from the stretch formed sheets, were used to lap join the sectors. The adhesive was reinforced with two layers of cotton fabric to assure good fill-in between the sectors and the strip.

A polyethylene bag was then placed over the assembly and a vacuum drawn such that the shell was held intimately against the master with a 10 PSI load over the entire surface. The master was not loaded, however, because atmospheric pressure existed over the convex and concave sides. The adhesive was room temperature cured for a minimum of 15 hours before further fabrication was performed.

It was then necessary to break vacuum by removing the bag in preparation for attaching the stiffener ring to the shell. However, during curing of the ring-to-shell adhesive, a vacuum was again applied between the shell and master to assure that the shell did not deviate from the master shape. The roundness and flatness of the stiffener ring edge which butted against the shell did not meet the tolerance and required cutting and filing to assure contact along the entire circumference. The difficulty here was that fund limitations did not allow adequate fixtures and tooling for fabrication of the ring. In any event, the shell shape did not suffer. The only objections to the resulting assembly were appearance and the effort required to correct the out-of-tolerance condition.

The adhesive was applied along the outer surface of the shell-ring junction and was reinforced with two layers of fibre glass cloth. The coefficient of thermal expansion of fibre glass reinforced adhesive closely matches that of aluminum, thus minimizing any thermal distortion effects on optical performance. Also, a reinforced junction is vastly stronger. A vacuum bag was applied over only the bonded area to assure a good bond contact. But the loading was not such that the shell or ring were distorted. This precaution was taken to avoid distorting the ring against the shell which would cause shell distortions after removal of the load. Again, the room temperature cure was uninterrupted for a minimum of 15 hours. Finally, the three mounting brackets were bonded to the ring with cotton fabric reinforced adhesive and vacuum bagged for an additional 15 hours minimum. The shell therefore had an accumulated cure time of 45 hours minimum with vacuum applied between shell and master. This was an adequate time to avoid post-cure distortions. All the adhesives used in fabrication of the three collectors were epoxies possessing shear strengths of 3000 PSI or more. The back side of the shell and the mounting ring and brackets were spray painted black. However, a flight prototype may not necessarily have a thermally "black" surface, depending,of course, on a thorough study of the heat transfer requirements of the assembly. Figure 3.9-2 shows front and back views of S/N 1 collector.

Optical inspection of S/N 1 indicated that the master was distorted. A special inspection device, as shown in Figure 3.9-3, was fabricated and the master shape was measured. To avoid expense, the device was supported on the master in the area of the vertex. This, of course, introduced errors into the measurements but the effects could be separated out and minimized by finding an optimum position for the three legs.

It was shown that the master was distorted during cure of S/N 1 and surface slope of up to 15 minutes existed. Figures 3.9-4, 3.9-5, and 3.9-6 show inspection results of three support methods, as identified on each sketch. The lines of constant elevation relative to the lowest (zero) can be used to get a good approximation of surface shape. Note that the master shape in Figures 3.9-4 and 3.9-5 is ellipsoidal and that the zero elevation lines are 90 degrees out of phase. This means that the master could be positioned to an optimum shape with minimum surface slope errors. The master was then supported at six adjustable support points on a circular ring. The resulting shape was much improved as Figure 3.9-6 shows. The maximum slope error in the first two support methods was about 14 minutes, and a large percentage of slope errors were near this value. The maximum error in the third support method was about 6 minutes, but only a small percentage of errors were near this value.

3.10 Inspection

Each of the collectors was optically inspected on the projected grid rig shown in Figure 3.10-1. The resulting data gives a direct measure of such surface slope errors as result from stretch forming, sector trimming and shell assembly. Errors due to Luder's lines and surface finish cannot be evaluated on this rig. The nature of the surface evaluation is similar to that obtained with the ray-trace method using a collimated light source. The major difference is that the entire collector inspection can be recorded by one photograph. This allows a panoramic study of the collector surface, and therefore provides a rapid evaluation of the surface characteristics.

Figures 3.10-2, 3.10-3, and 3.10-4 are the photographs of serial numbers 1 to 3, respectively. The clarity of the shadow in S/N's 2 and 3 is due to a better collector surface finish. Actually, three photographs of each, taken every 120°, are taken to give better resolution. This was necessary because the camera was off to one side of the rig. Any portion of the collector surface lying beneath a grid line can be studied, although the grid intersections provide the best points for measurement. Better resolution can also be obtained by enlarging the photographs up to 10:1.

The reduction of data is tedious, in that about 1650 grid intersections occur. Each deviation must be measured and converted into an angular error as follows:

$$\phi = \frac{\Delta x}{2 L}$$

where

ϕ = surface slope error, radians

Δx = displacement of grid shadow from pattern on screen, inches

L = distance between grid and screen

Figure 3.10-5 shows the measured Δx values for S/N 2. Figure 3.10-6 shows the converted surface slope errors.

The measured Δx values were taken directly from a full size rather than enlarged photograph. Coupled with the varying scale, due to the off angle position of the camera, the accuracy of data reduction was not as good as could be obtained. However, the measurements ought to be within 10 percent on the larger values and 20 percent on the smaller ones. The distribution curve on Figure 3.10-6 ought to be a good first approximation.

There are two points of interest in Figure 3.10-6. One, there are some sectors which are considerably better than others. Two, the distribution curve nodal point is not at zero surface slope error. Figure 3.10-7 shows the surface error distribution for the best and the worst sectors. Note that the nodal points again do not occur at zero, but that there is a considerable difference between the two. Also, sector #7-8 has two nodes.

Referring back to Figure 3.10-6, the sectors 6-7, 7-8 and 8-1 show a higher incidence of large surface errors than do the other five sectors. In checking back to the stretch form log sheets, it was noted that the three poor sectors were trimmed from stretched sheets numbers 1 and 2, whereas the others were from numbers 23, 27, 30 and 33. The significance here is that the earlier stretched sheets did not stretch over the die surface as well as the later ones because the techniques were still being established. Thus, the shape would be flatter for the earlier sheets and could account for this non-random distribution of errors between sectors.

It should also be noted that much of the cause for surface errors is a direct result of the substandard die. This can be seen in comparing optical inspection photos of the sectors before and after assembly of the shell. Figure 3.10-8 is a photo of sectors 5-6 and 6-7 before assembly. Identical deviations can be seen in comparing them with the same sectors in Figure 3.10-3. Figure 3.10-8 should be used only for identifying locations of the characteristic stretch form deviations. Absolute angular deviations cannot be taken from the photographs because it was difficult to position the single sectors such that each one or areas of a particular one had the same focal point. They serve the purpose of before-and-after comparison, however.

Additional panels will be stretch formed soon on another contract. It is expected that much improved surface quality will be achieved for two reasons. First, a die machined on a taped director controlled machine will provide a much improved forming surface. Secondly, aluminum alloy 3003 stock will be used. Thus, Luder's lines are expected to be less pronounced if not avoided.

For ease of data reduction, the shadow on the photographs was made more pronounced by tracing along the center of the grid lines with a pen. This made easier measurement from the traced line to the pattern reference lines.

Based on the projected grid inspection results, the S/N 2 collector is predicted to be the best optically and should be evaluated before the other two. The S/N 3 collector is comprised of a poorer grade of sectors because the selection was made from the last of the stretch formed lot, although the surface finish and reflectivity are better than S/N's 1 and 2. The geometric shape attributable to the shell assembly should be comparable, however, to S/N 2.

To determine a rough concentration ratio for these concentrators, a simple focal plane support was built as shown in Figure 3.10-9. The sun was manually tracked and the spot was measured by observing it with the aid of a filter. The spot for S/N 3 was somewhat elliptical and not greater than 1.5 inches on the major axis. However, it was difficult to get a measurement because the stainless steel target melted within 5 seconds. It is expected that the concentration ratio (with reasonably high efficiency) is in the 1500 to 2500 range.

Additional inspection and pertinent data are available in Figures 3.10-10A and 3.10-10B.

3.11 Other Collector Configurations

Collectors of other diameters and rim angles can be made by this same fabrication procedure. Stretch forming machine and aluminum stock limits would place an 8 sectored assembly upper limit at 12 feet in diameter. Larger diameters would be made, with only a small weight penalty, by increasing the number of sectors. The upper limit of collector diameter cannot be established without considering the trade-offs regarding the value of larger collectors versus the increased structural requirements due to larger areas exposed to acceleration and other loads.

The spin cast and taped director controlled machine methods would be used to obtain a die of sufficient accuracy for the stretch forming. A male replica would be cast from the spin casting should this method be used. In the larger diameters, the spin casting method would probably be the most economical. In both cases the accuracy has been shown to be adequate.

Thompson Ramo Wooldridge Inc.

CLEVELAND, OHIO, U. S. A.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Several problem areas were encountered during the contract that in sum total prevented the resulting collectors from meeting the optical requirements necessary for use with a thermionic converter. Because of fund limitations, the necessary corrective actions could not be taken. However, it is strongly felt that the fabrication method can provide the desired quality should these actions be made with additional work. The low specific weight of 0.58 lb/ft^2, compared to 1.0 lb/ft^2 for other materials of construction, and its nonmagnetic property are strong factors in favoring further development.

It is therefore recommended that additional work be done to refine the fabrication techniques. The proposed effort would include the following:

1. Fabricate a new 60 inch die, either by improved replica techniques or by use of the glass master properly reinforced.

2. Use aluminum alloy 3003 or 3004 to avoid Luder's lines.

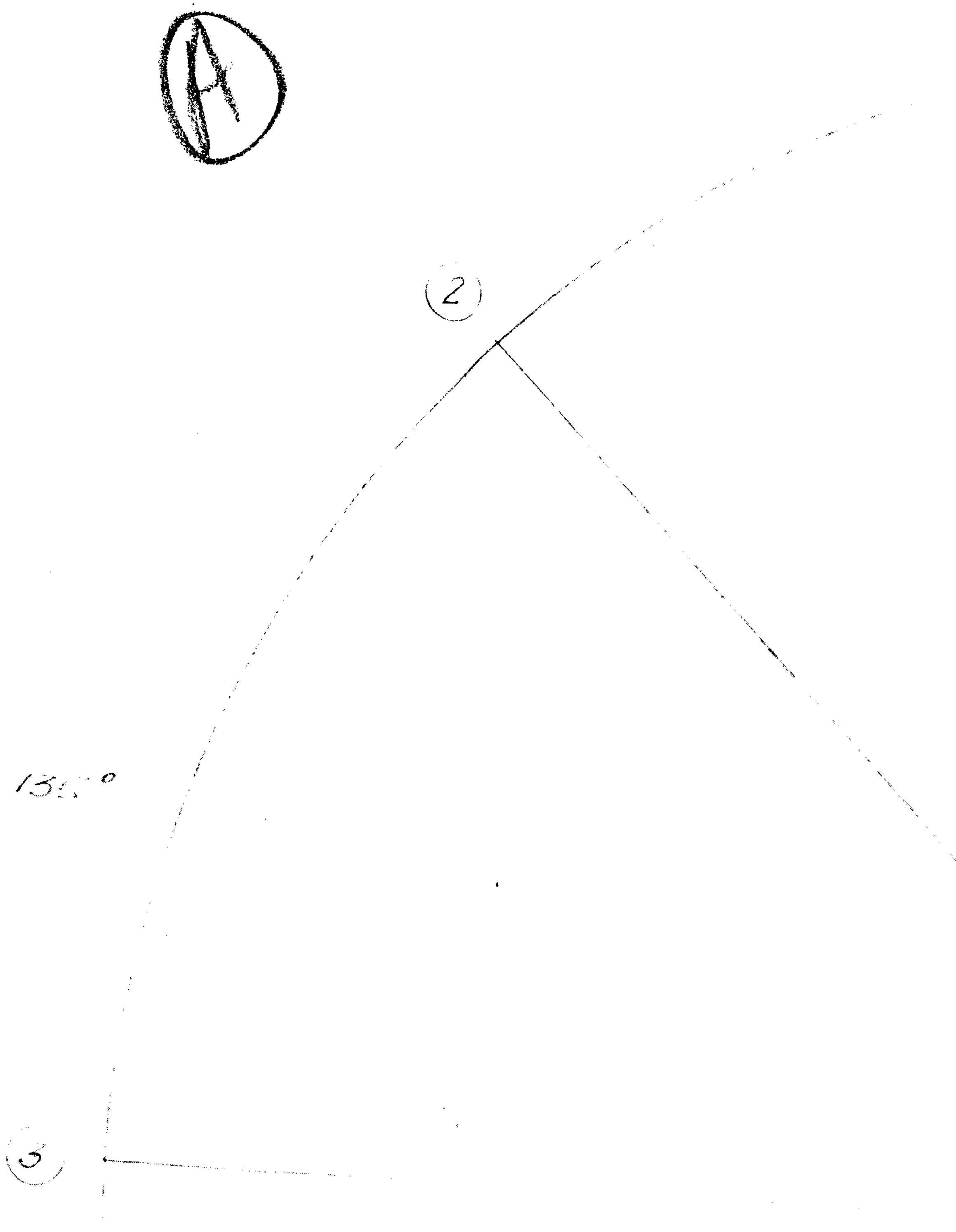
3. Modify the sector joint design to avoid surface errors.

4. Use improved surface finish improvement techniques wherein clean room facilities and modifications to the present coating method are used.

5. Conduct thermal and structural design stuides including limited experimental verification of the better design aspects.

6. Improve the stiffener ring and mount point design to reduce weight and provide required stiffness based on results of previous step.

7. Fabricate another 60 inch collector incorporating all the design improvements for evaluation at NASA Langley.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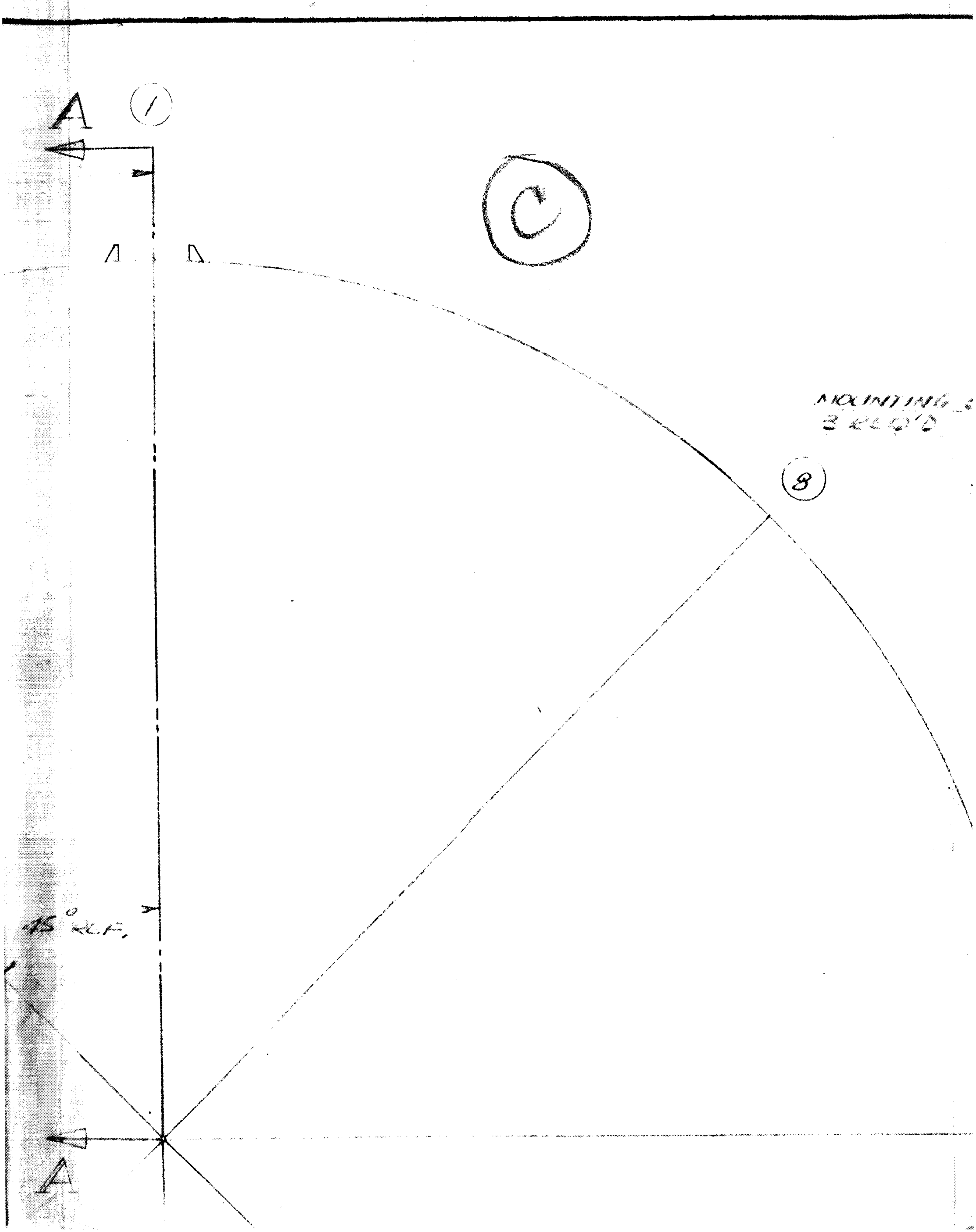
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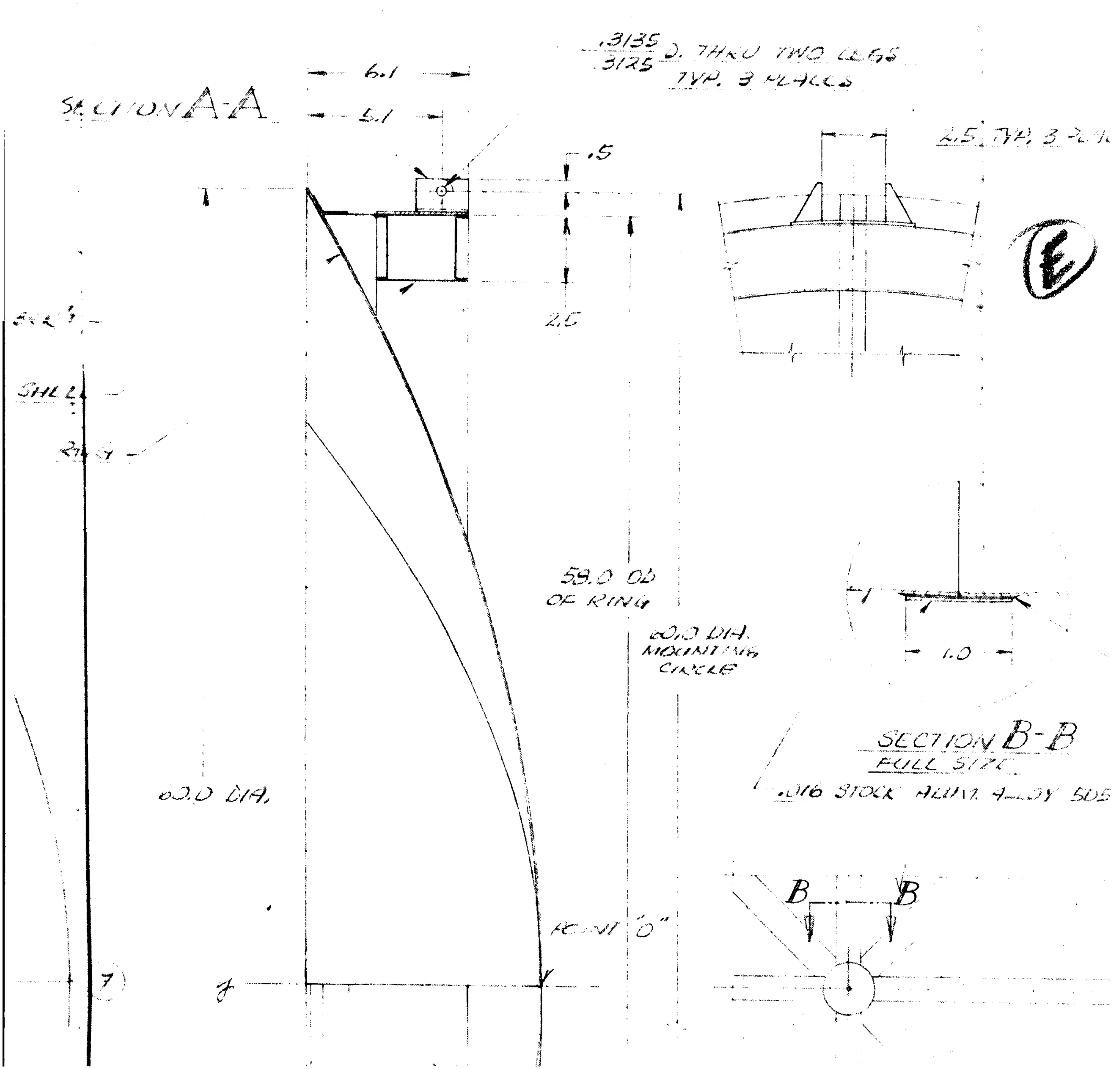

SECTION A-A
6.1
5.1
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D. THRU TWO LEGS
TYP. 3 PLACES
.5
2.5
58.0 OD
OF RING
60.0 DIA.
MOUNTING
CIRCLE
60.0 DIA.
POINT "O"
SHELL
RING
1.0
SECTION B-B
FULL SIZE
.016 STOCK ALUM. ALLOY 505
B
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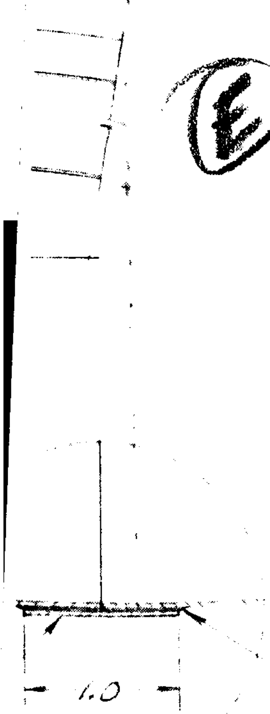
REVISIONS

SYM.	DESCRIPTION	D.C.N.	DRAWN	CHK'D	DATE

2.5 TYP. 3 PLACES

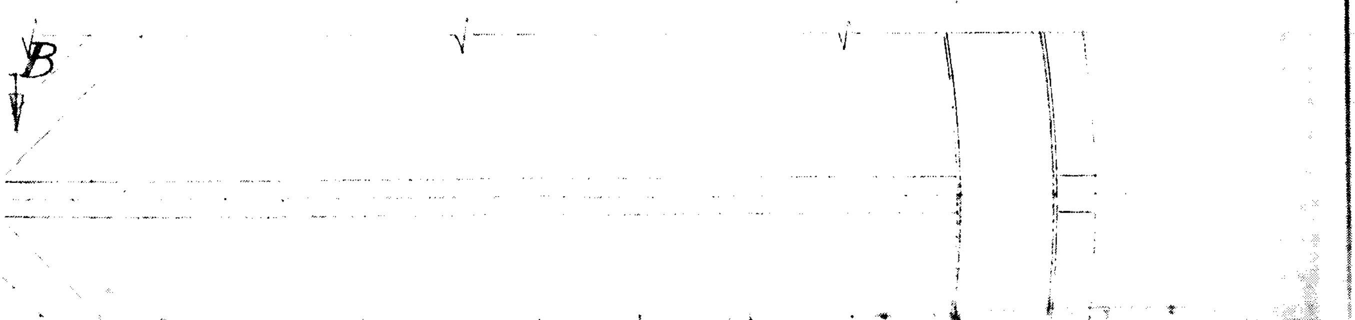
E

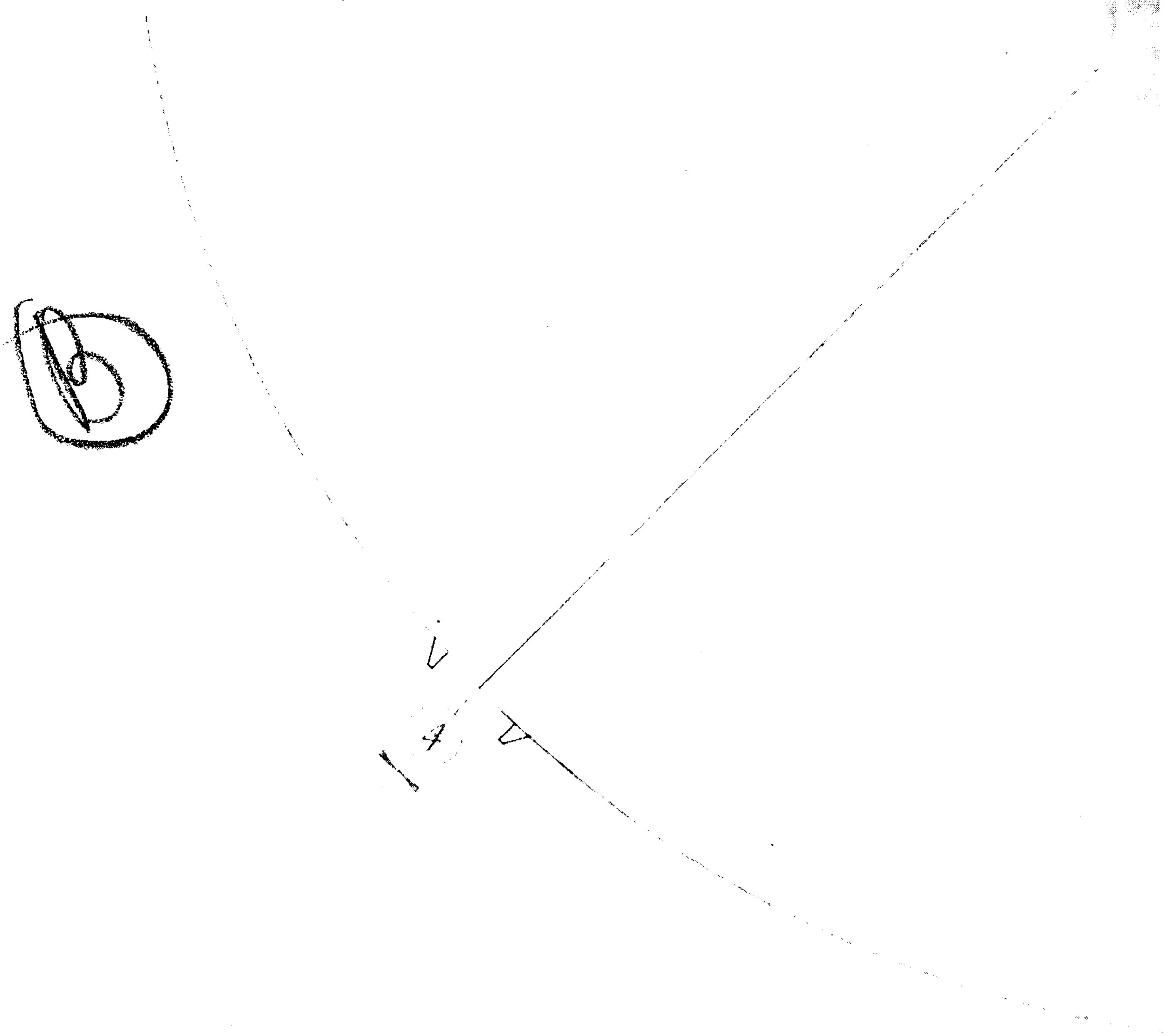
A



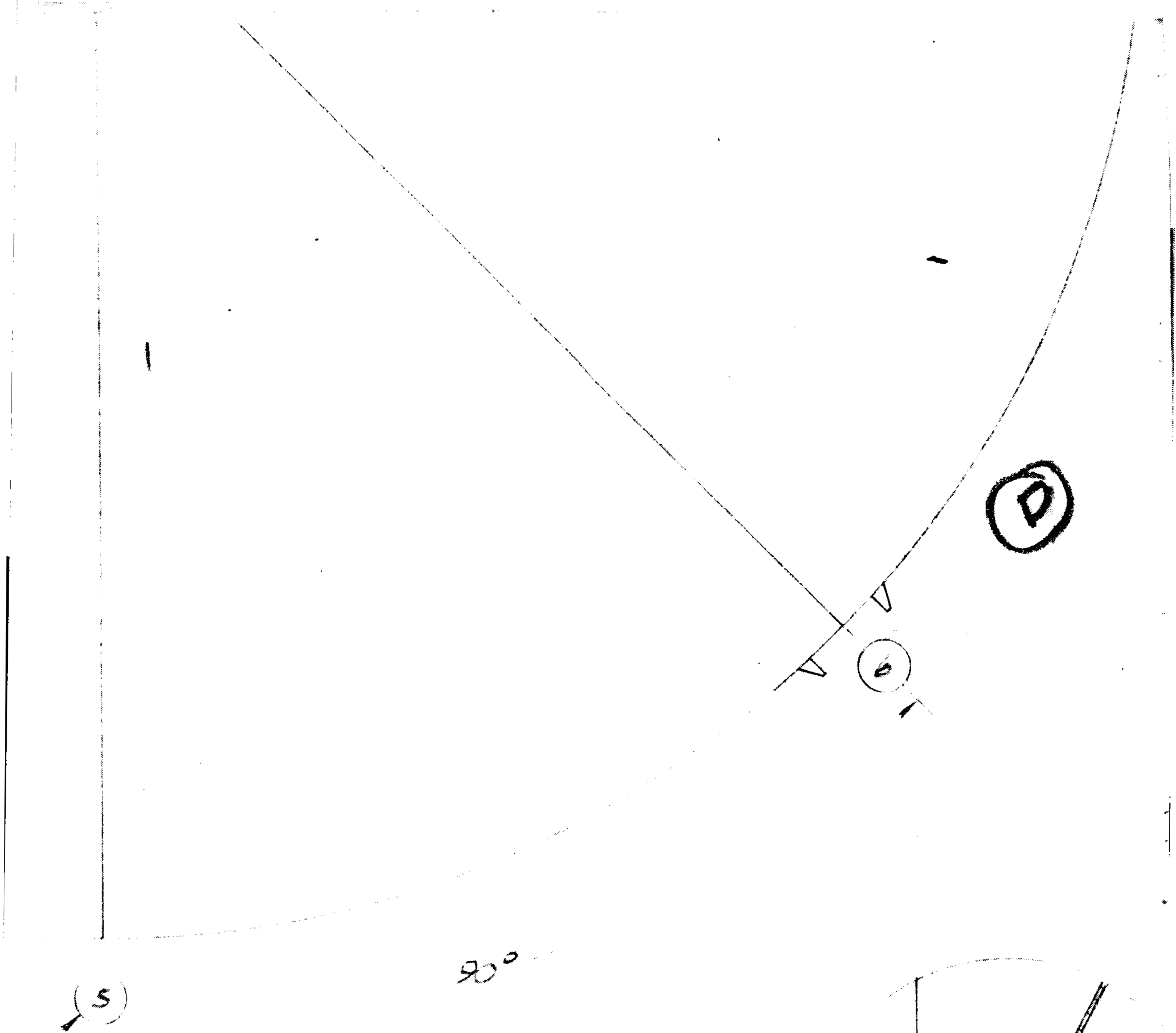
COTTON FABRIC REINFORCED EPOXY POLYMER, CURED AT ROOM TEMPERATURE FOR 15 HRS. MIN-IMUM BEFORE REMOVAL FROM TOOL

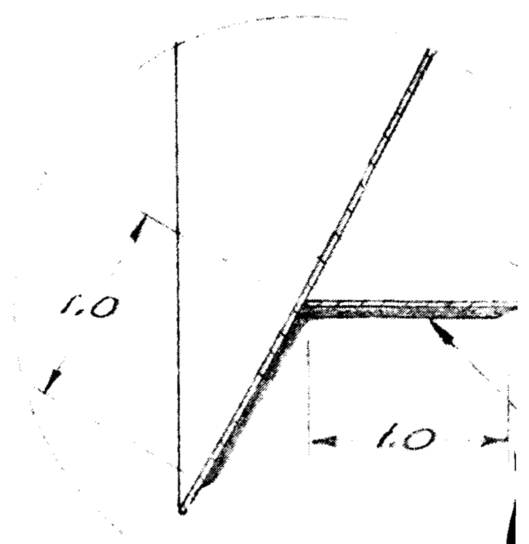
ECTION B-B
ULL SIZE
ALUM. ALLOY 5052-O





5. [illegible] IN [illegible] .00[illegible]
7. [illegible] TO BE [illegible] BY [illegible]
[illegible] TH.
6. SHELL, [illegible] BRACKETS TO BE ASSEMBLED
[illegible] REMOVED). EQUATION
[illegible] LINE O-Y; [illegible] = RAD[illegible]

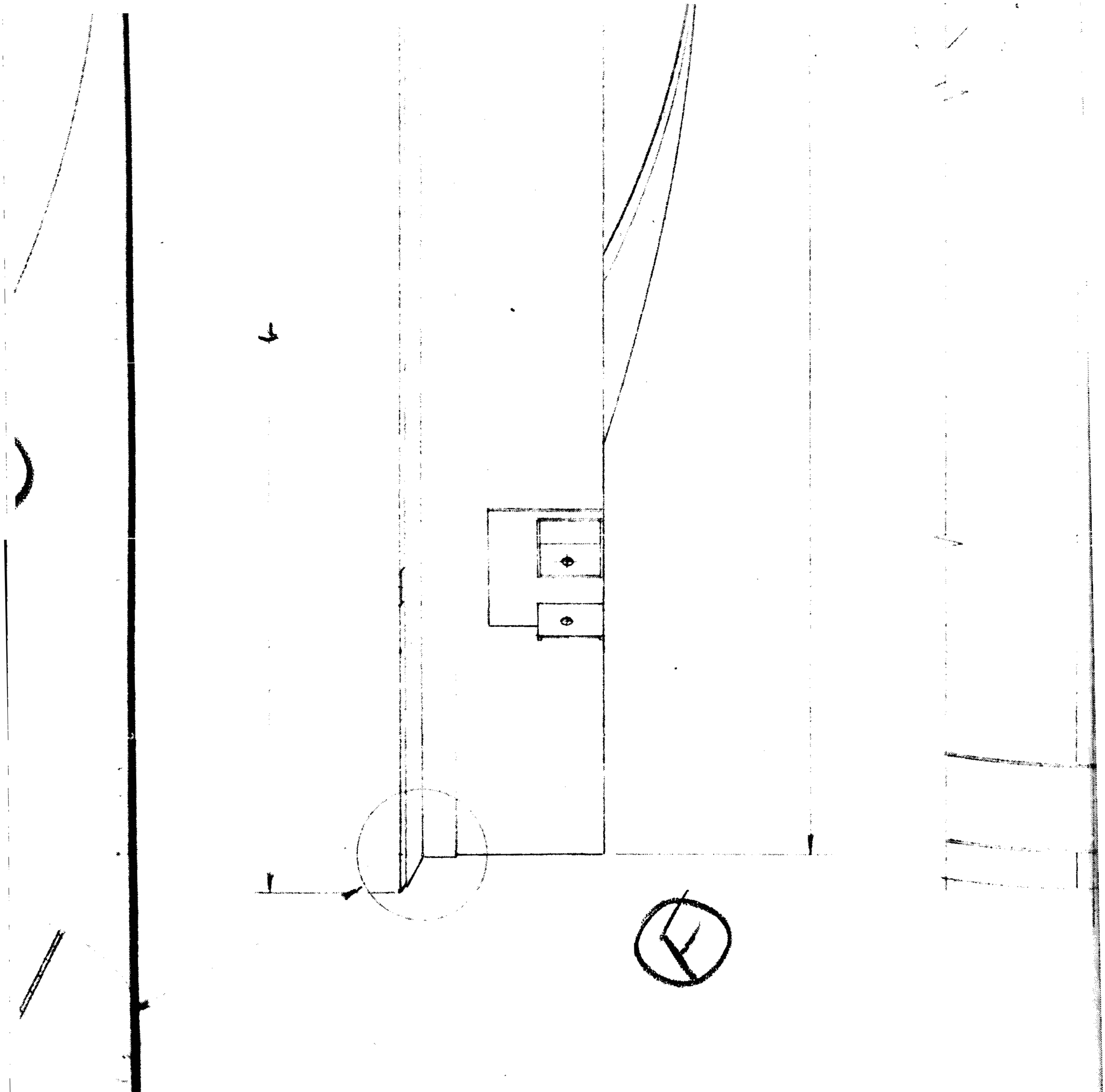




...AL STATIONS FOR REFERENCE IN
...AL INSPECTION PHOTOGRAPHS

...CKING [illegible] TO DETERMINE

... BACK FACE OF GLASS SEARCHLIGHT
... PARABOLOID CONTOUR OF SHELL IS
DIST., f = FOCAL LENGTH



FULL SIZE

1.0

-LASS FABRIC REINFORCED
-POXY POLYMER, CURED AT
-OOM TEMP, FOR 15 HOURS
-INIMUM BEFORE REMOVAL
-M TOOL

APPLICABLE SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED

DIMENSIONING AND TOLERANCING IN ACCORDANCE WITH MIL-STD-8.

THREAD DIMENSIONS AND DESIGNATIONS IN ACCORDANCE WITH HANDBOOK H-28 AND MIL-STD-9 RESPECTIVELY.

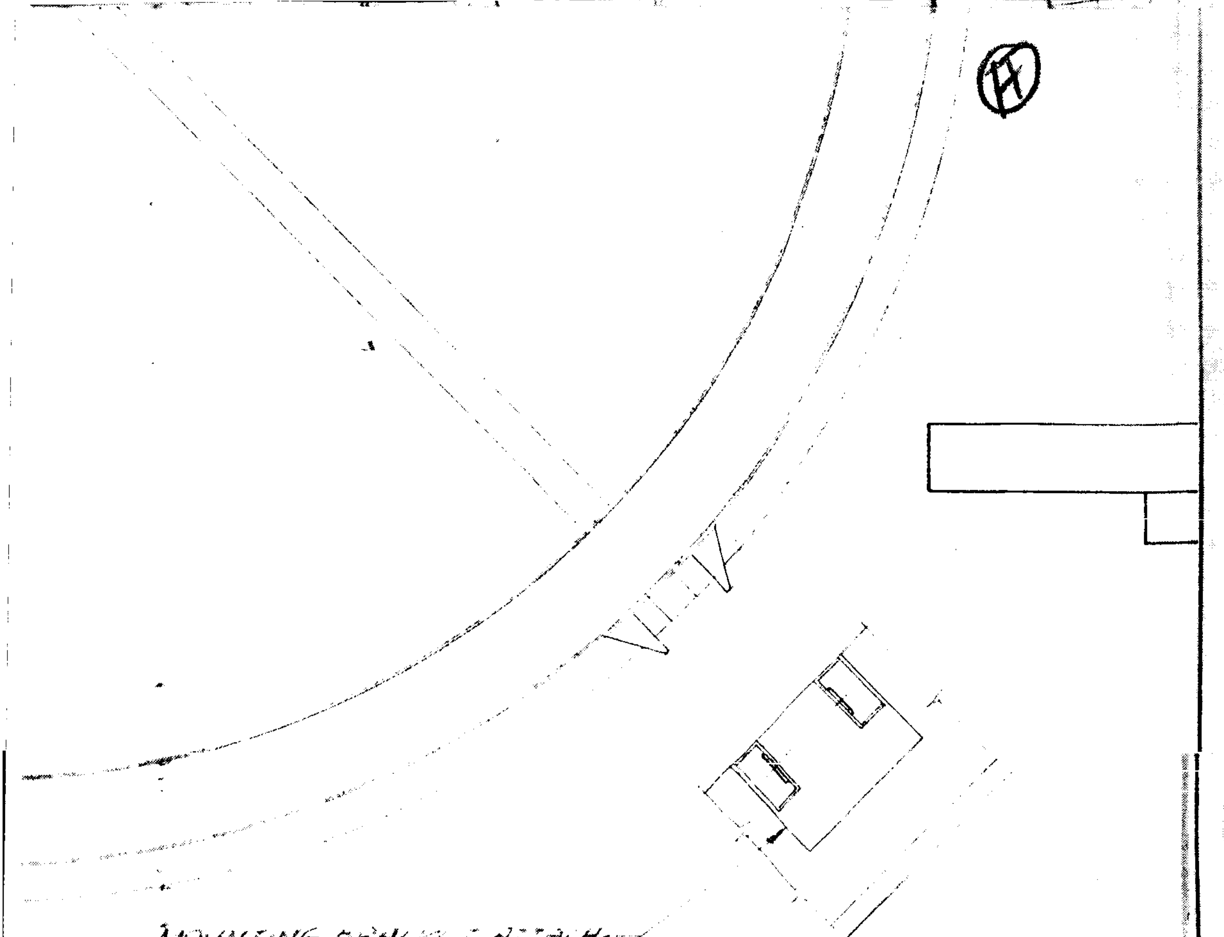
SURFACE ROUGHNESS SYMBOLS IN ACCORDANCE WITH MIL-STD-10.

PART MARKING IN ACCORDANCE WITH TRW SPEC. 02-5000.

UNLESS OTHERW
DIMENSIONS ARE
REMOVE ALL BURR
BREAK SHARP EDG
MACH. CORNERS .0
CAST RADII

TOLERANC

DECIMALS	F
.X = ± .1	A
.XX = ± .03	
.XXX = ± .010	C



MOUNTING BRACKET ATTACHED TO RING BY COTTON REINFORCED EPOXY POLYMER OVER ENTIRE CONTACT AREA. CURE AT ROOM TEMP. 15 HRS. MINIMUM BEFORE HANDLING

REQD.	REQD.	REQD.	REQD.	ITEM No.	PART NO.	DESCRIPTION	REF. NO.
				← ASSY DASH NO.		LIST OF PARTS	

SPECIFIED	DFTM.	CHC	8/10/62	MATL. & SPEC.	TREATMENT & HARDNESS	NEXT ASSY. OR REFERENCE NO. / DWG. SIZE D
INCHES	CHKD.					TAPCO GROUP THOMPSON RAMO WOOLDRIDGE INC. U. S. A.
.005/.015 .020 FILLET R.	APPD.			TITLE SOLAR CONCENTRATOR 60" DIAMETER NASA LANGLEY		
	ENG. APPD.					
ON-						
CTIONS ±	ENG. APPD.					DRAWING NO. 824231
LES ±	MATL. APPD.			SCALE 1/4	WEIGHT 11.3 LBS	MFG. CODE
E SHIFT ±	MFG.			DO NOT SCALE DWG.	DRAWING STATUS	H4-1 CODE 59875 / SHEET

FIGURE 3.3.1

ITEM	SERIAL Nº 1	SE
6. PROTECTIVE COAT	WITHOUT BREAKING VACUUM FROM PREVIOUS STEP APPLY SILICON OXIDE AT 7-8 $\times 10^{-4}$ TORR THICKNESS 3900 ANGSTROMS	SAME 180
7. REFLECTIVITY - TOTAL HEMISPHERICAL. OBTAINED BY INTEGRATING $R_\lambda I_\lambda$ CURVE WHERE: R_λ = SPECTRAL REFLECTIVITY I_λ = SPECTRAL SOLAR INTENSITY SPECIMEN COATED SAME AS SECTORS IN EACH LOT.	SPECIMEN NOT PREPARED	0.85
8. MOUNTING	AS SHOWN IN FIG. 3.3-1 EXCEPT RING DIA. IS ~55.4" INSTEAD OF 55.[illegible]" THEREFORE MOUNTING CIRCLE IS ~60.4" INSTEAD OF 60.0"	SAME CIR
9. FOCAL LENGTH - APPARENT. OBTAINED BY ADJUSTING FOCAL LENGTH DURING PROJECTED GRID OPTICAL INSPECTION UNTIL BEST SHADOW TO PATTERN ALIGNMENT OCCURS	26.2" SUBSEQUENT STUDY OF INSPECTION PHOTOS INDICATE FOCAL LENGTH WAS LESS BECAUSE OF INCORRECT SETTING OF SHADOW & SCREEN	25.6"

10. OPTICAL	SEE FIGURE 3.10-2	SEE CC AN SHI OC

SERIAL Nº 2	SERIAL Nº 3
SAME AS S/N 1 EXCEPT; 1800 Å	SAME AS S/N 1 EXCEPT; 2200 Å
0.88	0.99
SAME AS S/N 1 EXCEPT MOUNTING CIRCLE IS ~ 60.1"	SAME AS S/N 2
25.6"	25.6"

SEE FIGURES 3.10-3 3.10-5 3.10-6 3.10-7 3.10-8 CONCENTRATED SPOT WITH MANUAL TRACKING OF SUN WAS < 10" DIA. (VISUAL OBSERVATION)	SEE FIGURE 3.10-4

FIGURE 3.10

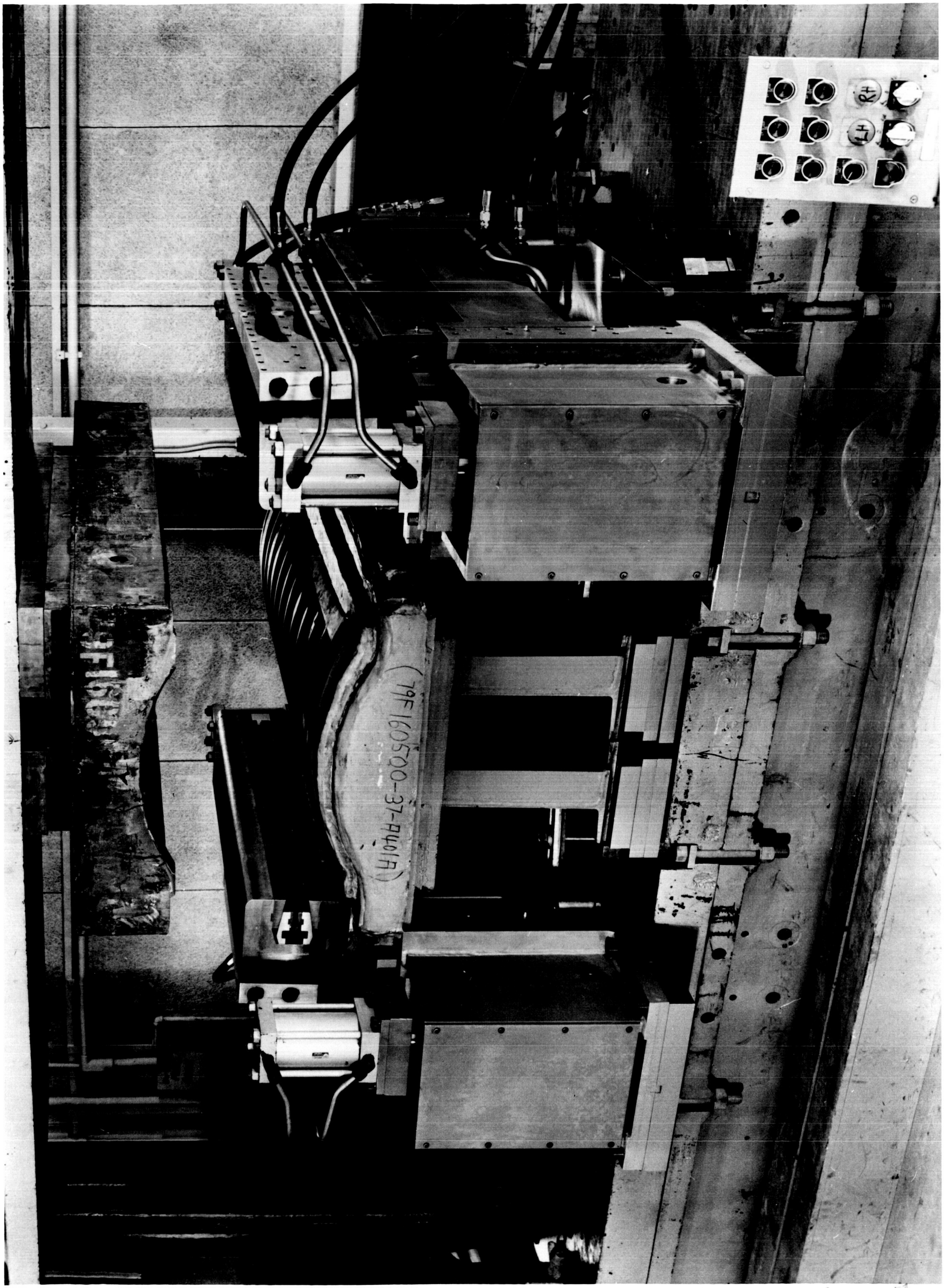
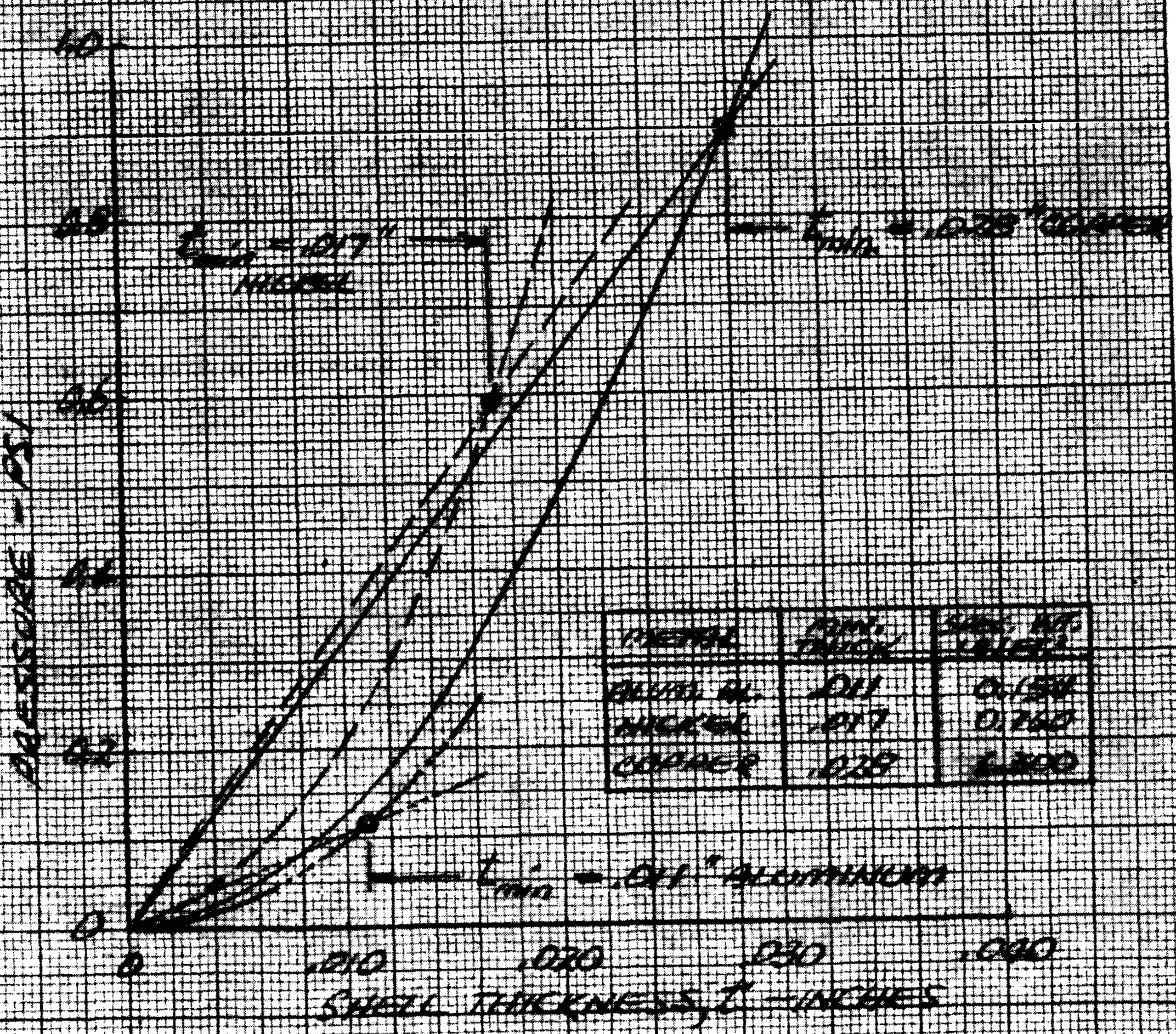


FIG. 3 4/2

CRITICAL PRESSURE VERSUS THICKNESS

$$p_{cr} = KE\left(\frac{t}{2R}\right)^{2}$$ CRITICAL PRESSURE (REF *) PARABOLIC CURVES

$$p_{y} = \frac{2\sigma t}{r}$$ EQUIV. PRESSURE STRAIGHT LINES



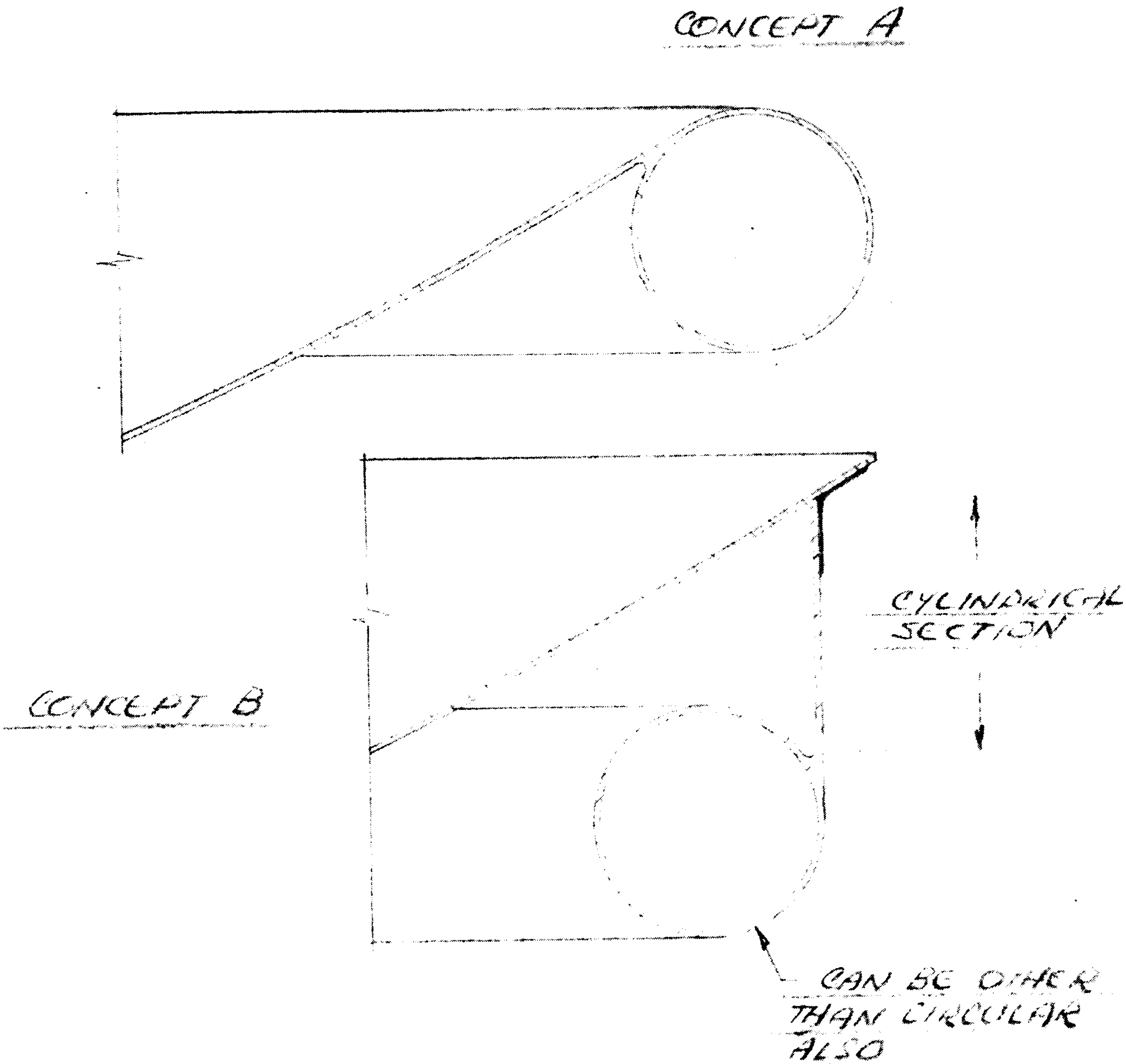
METAL	MIN. THICK	SHELL WT. LB/FT²
ALUM. AL.	.011	0.158
NICKEL	.017	0.760
COPPER	.028	1.300

* ASME PAPER 58-A-14

FIGURE 33-2

REVISIONS

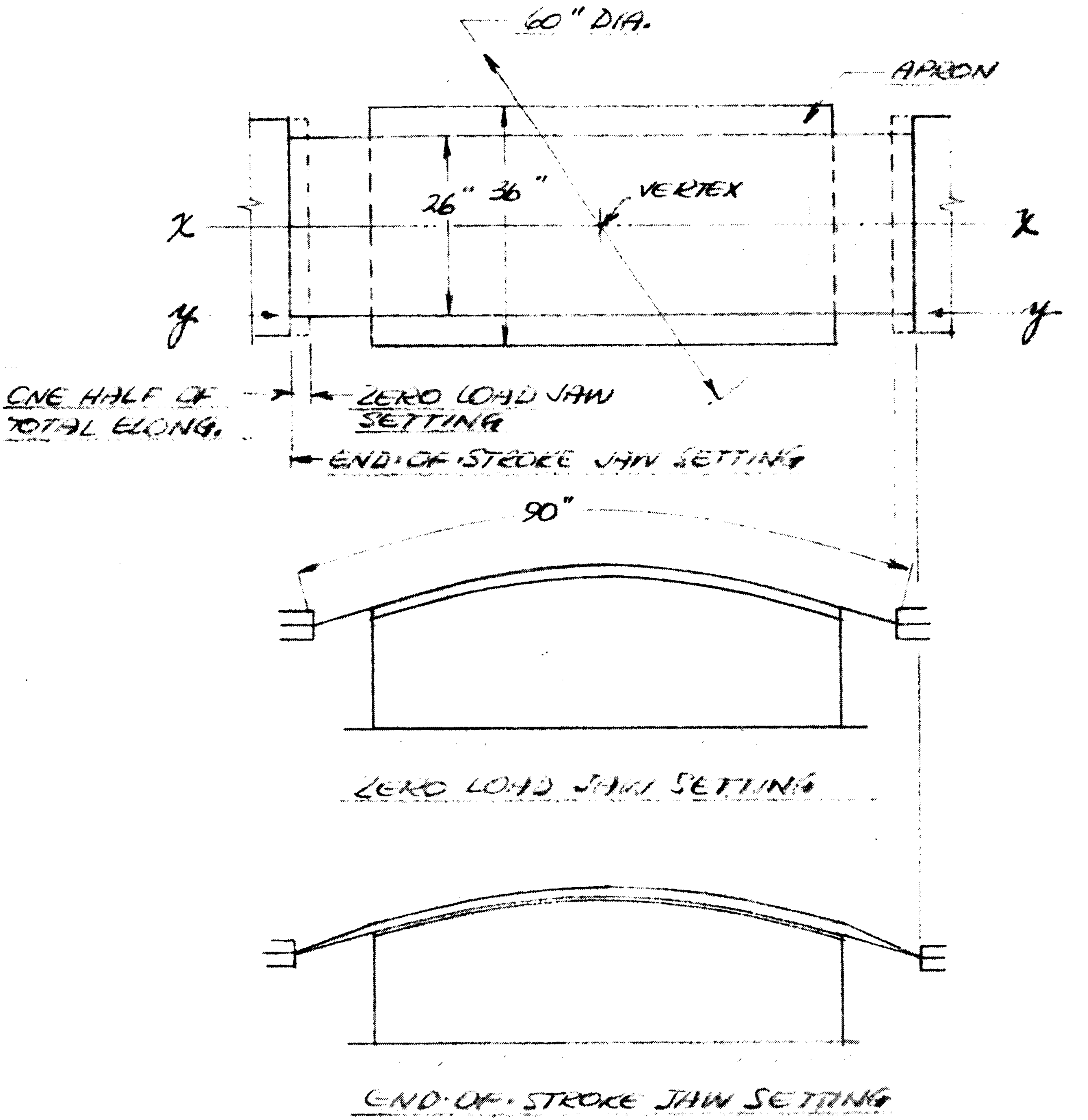
SYM.	DESCRIPTION	D.C.N.	DRAWN	CHKD.	DATE



UNLESS OTHERWISE SPECIFIED	DFTM.	MATL. & SPEC.	TREAT. & HDNESS.	NEXT ASSY. OR REF. NO. / DWG. SIZE A
DIMS. ARE IN INCHES. BREAK SHARP EDGES .005/.015. REMOVE ALL BURRS. MACHINED CORNERS .005/.020 FILLET R.	CHKD. / APPD. / ENG. APPD.	TITLE RING CONCEPTS		TAPCO GROUP THOMPSON RAMO WOOLDRIDGE INC. U. S. A.
TOLERANCES ON — DECIMALS .x = ±.1 .xx = ±.03 .xxx = ±.010 FRACTIONS ± ANGLES ±	ENG. APPD. / MATL. APPD. / MFG.	SCALE / DO NOT SCALE DRAWING	MFG. CODE / DRAWING STATUS	DRAWING NO. FIG. 3.3-3 / H4-1 CODE 59875 SHEET

REVISIONS

SYM.	DESCRIPTION	D.C.N.	DRAWN	CHKD.	DATE



UNLESS OTHERWISE SPECIFIED

DIMS. ARE IN INCHES.

BREAK SHARP EDGES .005/.015.

REMOVE ALL BURRS.

MACHINED CORNERS .005/.020 FILLET R.

TOLERANCES ON —

DECIMALS	FRACTIONS
.X = ± .1	±
.XX = ± .03	ANGLES
.XXX = ± .010	±

DFTM.

CHKD.

APPD.

ENG. APPD.

ENG. APPD.

MATL. APPD.

MFG.

MATL. & SPEC.

TREAT. & HDNESS.

TITLE

SCALE

MFG. CODE

DO NOT SCALE DRAWING

DRAWING STATUS

NEXT ASSY. OR REF. NO.

DWG. SIZE A

TAPCO GROUP

THOMPSON RAMO WOOLDRIDGE INC.

U. S. A.

DRAWING NO.

FIG. 3.4-1

H4-1 CODE 59875

SHEET

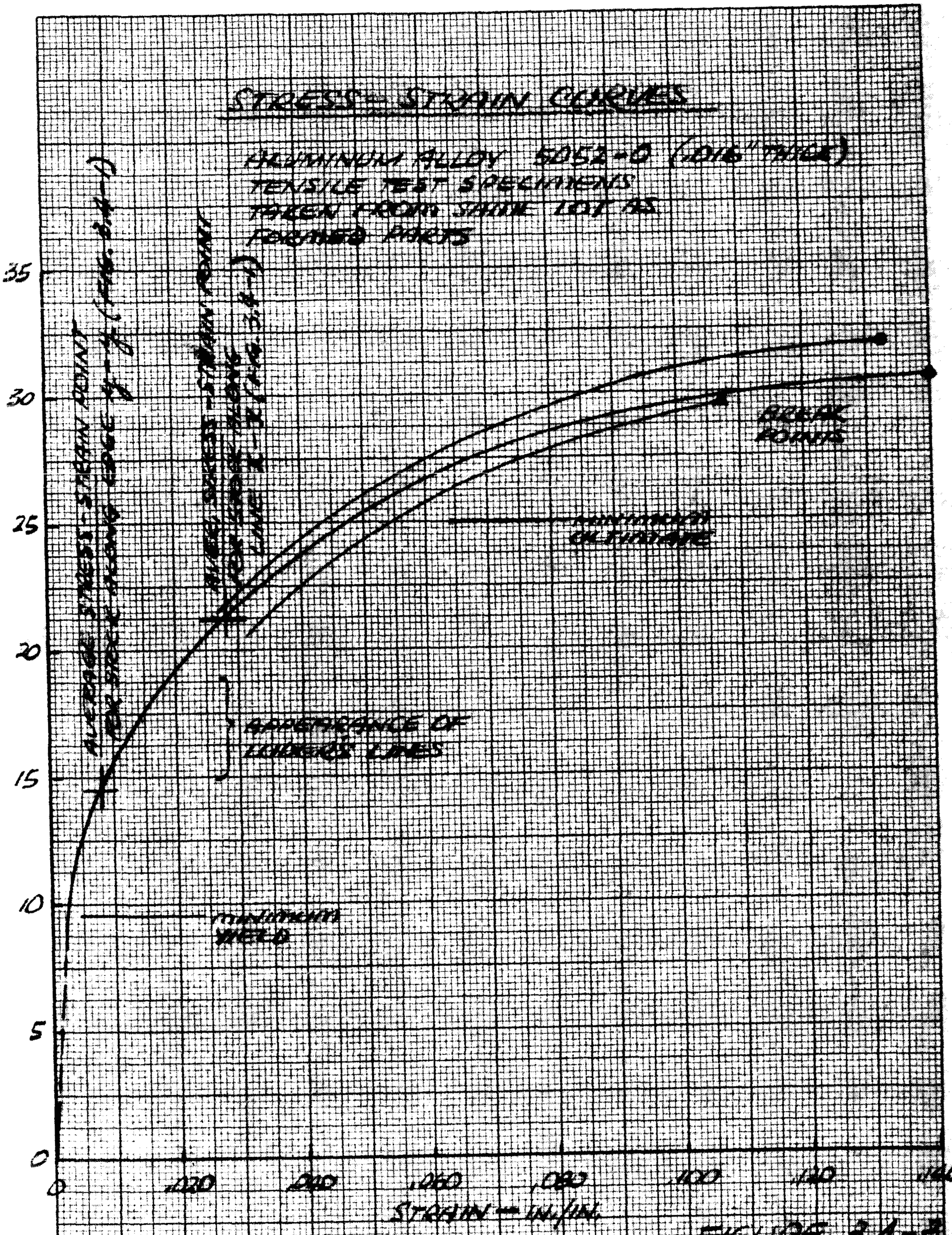

STRESS - STRAIN CURVES
ALUMINUM ALLOY 5052-0 (.016" THICK)
TENSILE TEST SPECIMENS
TAKEN FROM SAME LOT AS
FORMED PARTS
AVERAGE STRESS-STRAIN POINT FOR STOCK ALONG EDGE Y-Y (FIG. 3.4-1)
AVER. STRESS-STRAIN POINT FOR STOCK ALONG LINE X-X (FIG. 3.4-1)
BREAK POINTS
MINIMUM ULTIMATE
APPEARANCE OF LUDERS' LINES
MINIMUM YIELD
35
30
25
20
15
10
5
0
0
.020
.040
.060
.080
.100
.120
.140
STRAIN — IN./IN.

FIGURE 3.4-3

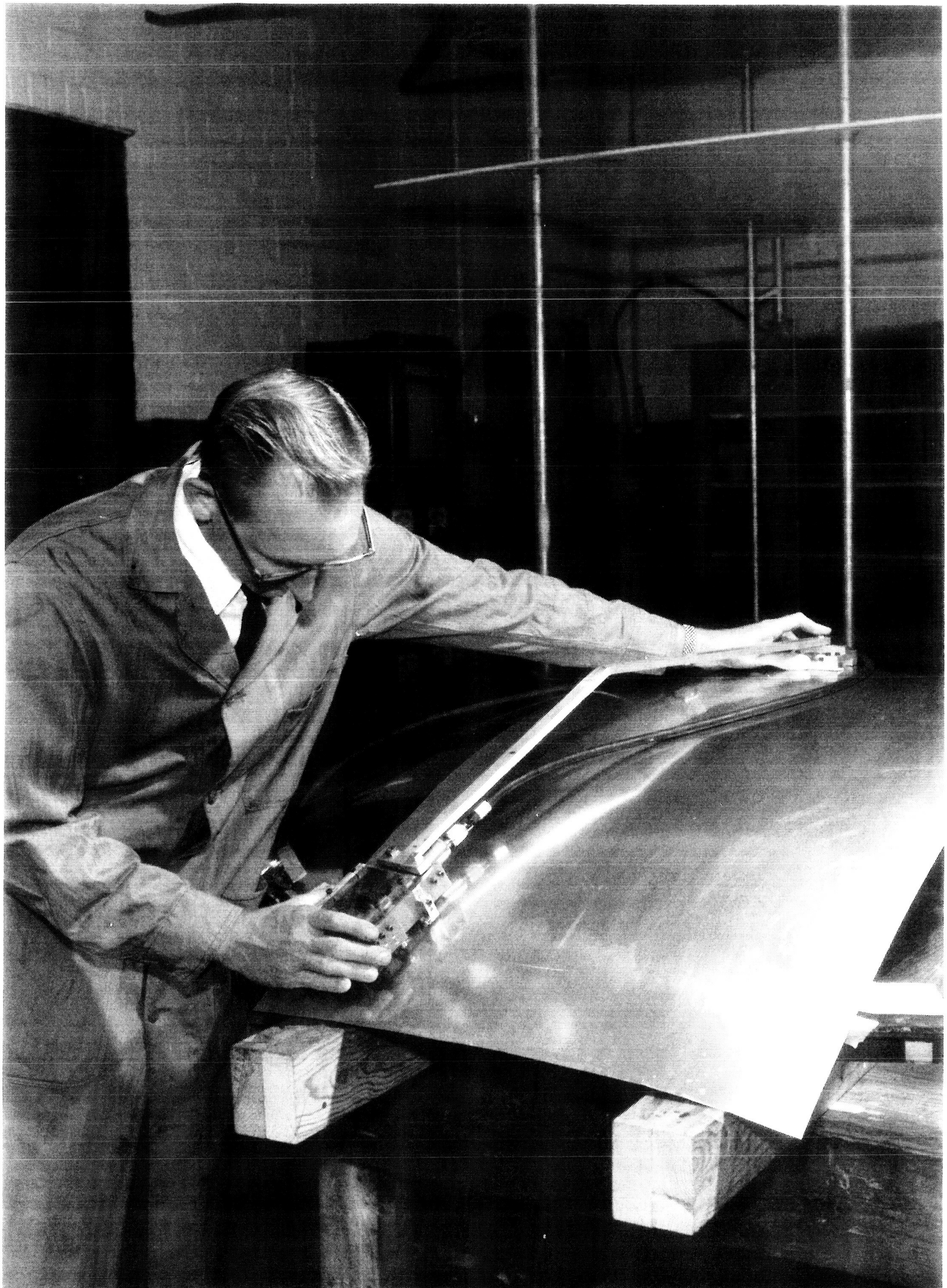
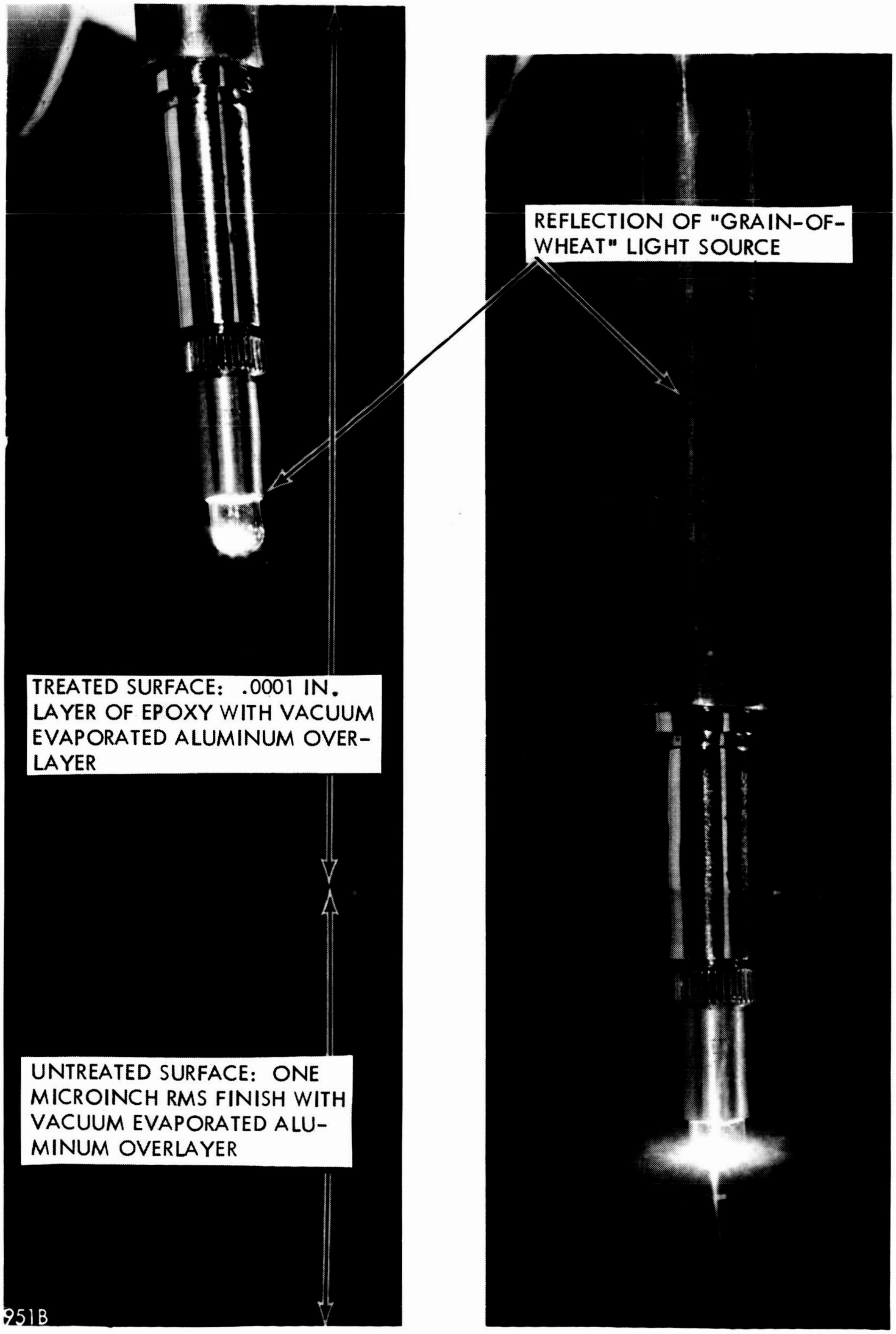


FIG. 3 5/1-6



EPOXY LAYER SURFACE IMPROVEMENT TECHNIQUE

FIG. 3 . 6/1

951 β

FIG. 3 9/1

A

6 7

				.1 .25 .2 .1 . .3	.5 .65 .4 .35 .3 .4	.75	
			.1 .5	.2 .25 .15 .1 .15 .15	.5 .75 .65 .5 .4 .5	.55 .7 .6 .5	
			.15 .25 .3 .45	.15 .15 .15 .25 .15 .15	.15 .2 .5 .6 .5 .45	.7 .6 .6 .3 .6 .5	
		.1 .15	.2 .4 .15 .25 .2 .3	.35 .1 .1 .1 .1 .15	.15 .15 .2 [illegible] .5 .3	.6 .35 .3 .5 .4 .3	.3 .8
		.2 .15	.15 .15 .25 .25 .3 .3	.3 .1 .15 .15 .1 .15	.1 .15 .25 .25 .5 .5	.5 .5 .45 .4 .2 .4	.2 .25
		.15 .1 .1	.15 .1 .3 .3 .4 .3	.3 . . 0 .15 .15	.1 .15 .2 .2 .3 .3	.4 .5 .4 .4 .5 .6	.7 .8
		. . .25 .2	.15 .15 .15 .2 . .2	.5 .15 .1 .1 .1 .1	.2 .2 .2 .15 .25 .2	.45 .3 .5 .15 .3 .6	.6 .6
		.05 .1 .15 .35 .1	.1 . .45 .3 .25 .5	.5 .15 .1 .1 .1 .1	.15 .15 .15 .20 .15 .15	.25 .5 .12 . . .65	.65 .7
		.1 .05 .1 .15 .4 .15	.15 .1 .15 .1 .1 .35	.25 .3 .1 .1 .15 .1	. .1 .15 .15 .2 .3	.3 .3 .2 .6 .75 .3	.65 .8
	.2	0 0 .1 .25 .1 .1	.1 0 .15 .2 .25 .4	.5 .2 .05 .05 .1 .05	.1 .1 .15 .15 .2 .25	.3 .35 .1 .7 .6 .6	.5 .6
5	.2	.1 .05 .1 .1 .1 .05	0 .1 .05 .36 .2 .25	.25 .2 .1 0 .15 .15	.15 .1 .15 .15 .2 .3	0 . .7 .6 .6 .5	.5 .6
	.1 .2	.15 .1 .15 .15 .15 .15	.1 .1 .05 .15 .2 .2	.25 .2 .1 .1 .1 .05	.1 .1 .1 .1 .15 .15	.15 .3 .7 .6 .6 .5	.4 .5
	0 .2 .1	.05 .1 .1 .15 .15 .1	.1 .1 .1 .2 .2 .25	.3 .15 .15 .15 .1 .1	.1 .1 .15 .15 .15 .2	.2 .6 .6 .6 .5 .4	.25 .3
	.1 .25 .2	.2 .15 .15 .15 .1 0	.1 .05 0 0 .05 .1	.2 .15 .15 .15 .05 .1	.15 .15 .1 .1 .15 .1	.2 .6 .3 .3 . .5	.35 .15
	.1 .15 .15 .3	.4 .1 .15 .1 .1 .05	.05 .15 .1 .1 0 .15	.1 .05 .1 .15 .1 .1	.1 .1 .1 .15 .1 .2	.45 .3 .25 .3 .2 .1	.15 .2
	.05 .2 .5 .2	.3 .3 .15 .1 .1 .1	.1 .1 .1 .1 .1 .1	.1 .15 .2 .1 .1 .15	.1 .1 .1 .15 .15 .2	.6 .15 .15 .15 .2 .15	.1 .2
	0 .05 .1 .15 .15	.15 .4 .1 .15 .15 .05	.1 .2 .1 .1 . .	.1 .1 .15 .1 .15 .15	.1 .1 .15 .1 .3 .25	.3 .3 .15 . .15 .15	. .1
	0 .05 .1 .1 .1	.1 .15 .2 .2 .3 .2	.15 .1 .1 .1 . 0	.15 .05 .05 .1 .5 .15	.05 .05 .1 .15 .35 .1	.1 . .2 .1 .15 .1	.1 .2
	.1 .1 .1 .15	.1 .2 .3 .05 .3 .25	.2 .2 .1 .1 .1 0	.25 .1 .1 .15 .2 .1	.05 .05 0 .25 .1 .5	.15 .1 .1 .1 .1 .25	.2 .1
	.05 .2 .1 .1 .05	.1 .1 .2 .1 .1 .2	.2 .2 .25 .25 .1 .15	0 .05 .05 .05 .1 .15	0 .1 .1 .2 .15 .15	.2 .2 .1 .1 .2 .1	.25 .2
	.2 .2 0 .1 .05	.15 .15 .3 .1 .05 .1	.1 .15 .1 .15 .1 .05	.1 .15 .15 .15 .1 .1	.1 .1 .3 .2 .1 .1	.1 .2 .15 .3 .5 .7	.6 .5
	.1 .15 .15 0 .05	.1 .05 .15 .1 .05 .1	.1 .05 .1 .1 .2 .15	.05 .1 .1 .1 .15 .1	.1 .1 .15 .15 .15 .15	.25 .5 .6 .7 .6 .6	.6 .5
	.1 .1 .15 .1 .1	.1 .15 .2 .1 .1 .2	.15 .1 .15 .2 .2 .1	.1 .1 .1 .1 .1 .15	.15 .15 .1 .15 .2 .3	.35 .35 .4 .5 .56 .6	.6 .6
	.15 .1 .1 .1 .1	.1 .2 .1 .1 .15 .15	.25 .2 .15 .15 .1 .1	.1 .1 .1 .25 . .1	.7 .15 .5 .35 .35 .2	.3 .3 .35 .4 .45 .5	.5 .4
	.15 .1 .1 .1 .1	.15 .16 .5 .15 .2 .1	.15 .2 .15 .1 .1 .1	.1 0 .1 .25 .1 .1	.15 0 .15 .2 .15 .3	.3 .3 .1 .15 .15 .2	.2 .2
	.1 .15 .2 .15 .2	.35 .3 .3 .5 .4 .2	.2 .2 .1 .15 .2 .25	.1 .15 .3 .25 .15 .1	.25 .3 .15 .15 .2 .15	.15 .2 .15 .15 .1 .1	.05 .1
	.15 .15 .15 .5 .4	.5 .5 .4 .3 .15 .1	. .2 .2 .15 .15 .2	.15 .15 .15 .15 .1 .1	.15 .25 .3 .25 0 .1	.15 .1 .15 .2 .15 .15	.15 .1
	.2 .25 .2 .15 .15	.3 .2 0 .1 .1 .15	.15 .15 .2 .15 .1 .1	0 .2 .15 0 .2 .2	.1 .1 .15 .15 .2 .3 .3	.1 .1 .2 .05 .1 .1	.1
	.3 .45 .1 .1 .2	.2 .25 .35 .1 .2 .2	.2 .2 .3 . . .	.1 .1 0 . .15 .1	.1 .1 .1 . . .3	.3 .2 .1 .1 .15 0	.1 .15
4	.15 .15 .1 .15 .2	.25 .25 .25 .2 .2 .2	.1 .1 .1 .1 .05 .05	.15 .15 0 .1 .15 .15	.1 .1 .15 .15 .35 .15	.1 .3 .3 .1 .1 .15	.25 .2
	.1 .15 .25 .2 .15	.05 .2 .05 .1 .1 .1	.05 .15 .1 .15 0 .1	.1 .5 .2 .2 . .	.05 .05 .1 .15 .1 .1	.2 .3 .3 .2 0 .2	.1 .3
	.05 .1 .1 .05	.15 .1 .05 .05 .1 .1	0 .1 .1 .05 0 .1	.05 .05 .15 .15 .15 .1	.1 .1 .05 .2 .2 .2	.15 .15 .2 .15 .3 .25	.15 .2
	.05 .1 .25 .2	.15 0 .15 .15 .2	.1 .1 .1 .15 .1 .15	.05 .35 .3 .1 .1 .	.15 .1 0 .3 .2 .15	.2 .15 .3 .35 .2 .4	.4 .3
	.15 0 .1	.05 .2 .1 .1 .05 .2	.15 .15 .15 .15 .1 .3	.25 .4 .3 .15 .15 .1	.1 .15 .05 .15 .2 .2	.2 .2 .15 .25 .4 .4	.5 .6
	.1 .05 .15	.05 .15 .1 .15 .1 .15	.15 .15 .15 .1 .1 .3	.3 .35 .3 .25 .1 .1	.1 .15 0 .1 .3 .25	.4 .1 . .5 .3 .2	.25 .3
	.3 .1	.05 .05 .15 .35 .2 .15	.1 .15 .15 .15 .1 .1	.5 .3 .2 .15 .1 .1	0 .1 .05 .15 .25 .6	.4 .3 .3 .1 .15 .15	.3 .1
	.15 .15	.15 .15 .14 .5 .1 .1	.15 .15 .05 .15 .1 .3	.2 .2 .15 . . .	.1 .1 .15 .15 .15 .6	.25 .1 .15 .15 . .	. .1
	.2	.1 .15 .1 .1 .15 .1	.15 .15 .15 .1 .1 .3	.35 . .15 .15 .15 .	. .2 .2 .1 .3 .6	.2 .1 .15 .2 . .	
		.1 .15 .2 .2 .1 .1	.1 .3 .4 .1 .2 .4	.2 .6 .35 .15 .1 0	.1 .15 .4 .1 .3 .3	.3 .15 .15 .05 .15 .2	.15 .3
		.15 .2 .2 .15 .1	.15 .15 .25 .05 .4 .15	.1 .2 .2 .15 .15 .1	.05 .3 .1 .1 .1 .5	.3 .1 .2 .1 .1 .1	.1 .1

B

.15	.1	0	.5	0	.1	.3	.3	.25	.25	.2	.1	.15	.15	.1	.05	.1	.15	.2	.15	0	.2	.3	.1	.1	.15	.1	.1	.1
	.2	.1	.15	.1	.15	.3	.1	.1	.1	.2	.15	.15	.1	.15	.1	.1	.2	.15	.1	0	.1	.1	.1	.15	.3	.1	.15	.1
		[illegible]	.05	.1	.1	.15	.3	.25	.5	.15	.2	.15	.15	.15	.1	0	.05	.1	0	.05	.1	.15	.1	0	.05	.15		
				.1	.05	.1	.1	.25	.15	.15	.15	.1	.1	.1	.15	.15	.2	.05	.1	.15	.1	.1	.1	0	.05			
						.1	0	.15	.15	.15	.15	.2	.5	.5	.25	.1	.1	.05	.05	.15	.15	.1	.1					
								.2	.15	.1	.05	.2	.1	.15	.15	.15	.15	.1	.05									

3

2

D

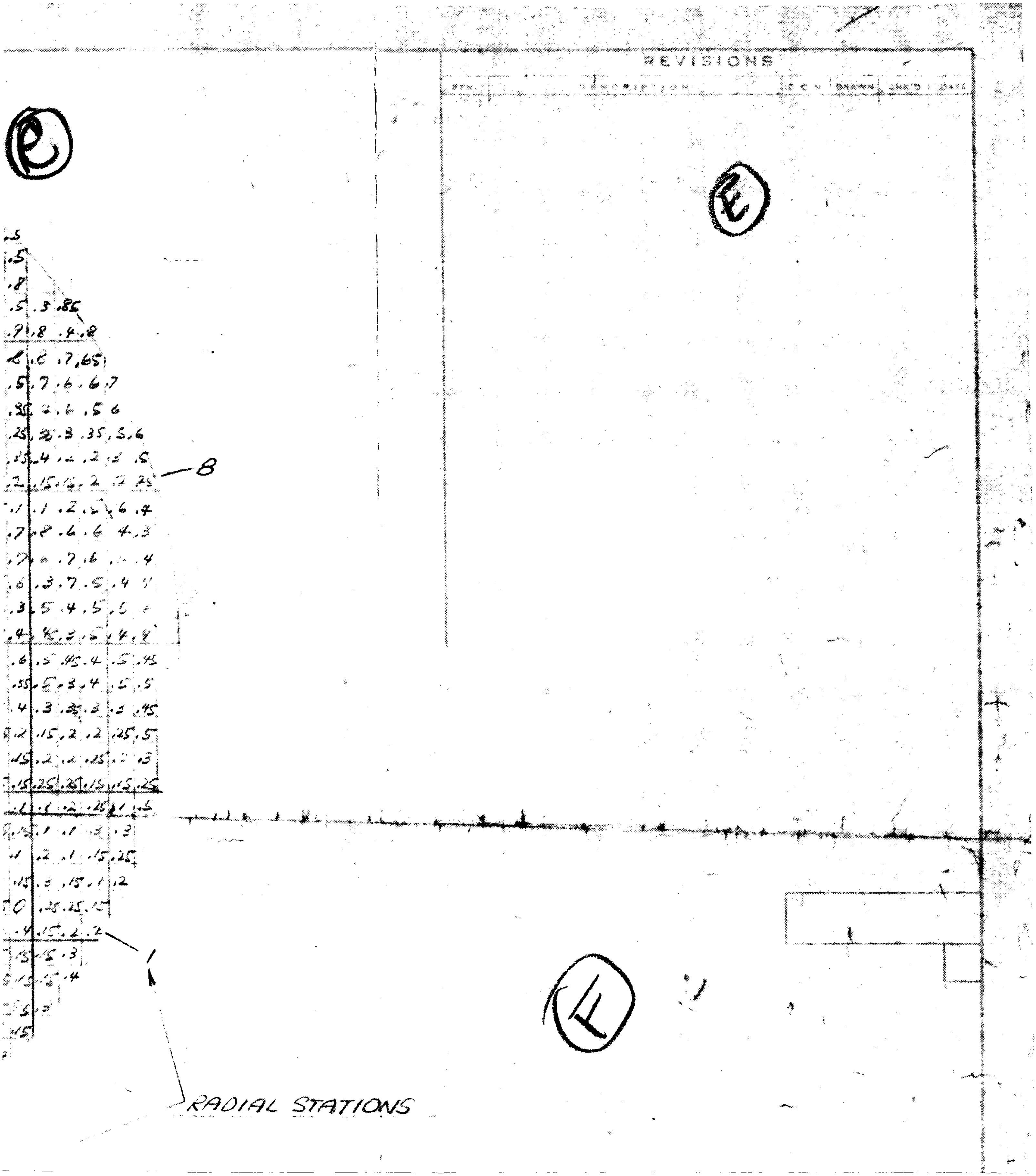
3. EQUATION FOR OBTAINING SURFACE SLOPE ~~ERROR~~ :

$\phi = \Delta x / 2L$; WHERE ϕ = ANGLE (RADIANS); L = DIST. BETW. GRID & SCREEN

2. THE ABOVE VALUES ARE DEVIATIONS OF PROJECTED SHADOW (Δx) FROM PATTERN IN INCHES. VALUES WERE MEASURED AT EACH INTERSECTION OF GRID LINES

1. COLLECTOR VIEWED FROM CONVEX SIDE (REAR)

APPLICABLE SPECIFICATIO
UNLESS OTHERWISE SPECIFI
DIMENSIONING AND TOLERANCING
ACCORDANCE WITH SPEC MIL-STD


REVISIONS
DESCRIPTION
DRAWN
DATE
E
F
8
RADIAL STATIONS

RADIAL STATIONS

ITEM NO.	REQD	PART NO.	DESCRIPTION	REF NO.

LIST OF PARTS

MAT'L & SPEC | TREATMENT & FINISHES | NEXT ASSY OR REFERENCE NO. | DWG SIZE C

TAPCO GROUP
THOMPSON RAMO WOOLDRIDGE INC.
U. S. A.

TITLE
PROJECTED GRID DEVIATIONS ; S/N 2
NASA LANGLEY 60" COLL

DRAWING NO.
FIGURE 3.10-5

SCALE | WEIGHT | MFG. CODE

DO NOT SCALE DWG | DRAWING STATUS | CODE 59875 | SHEET

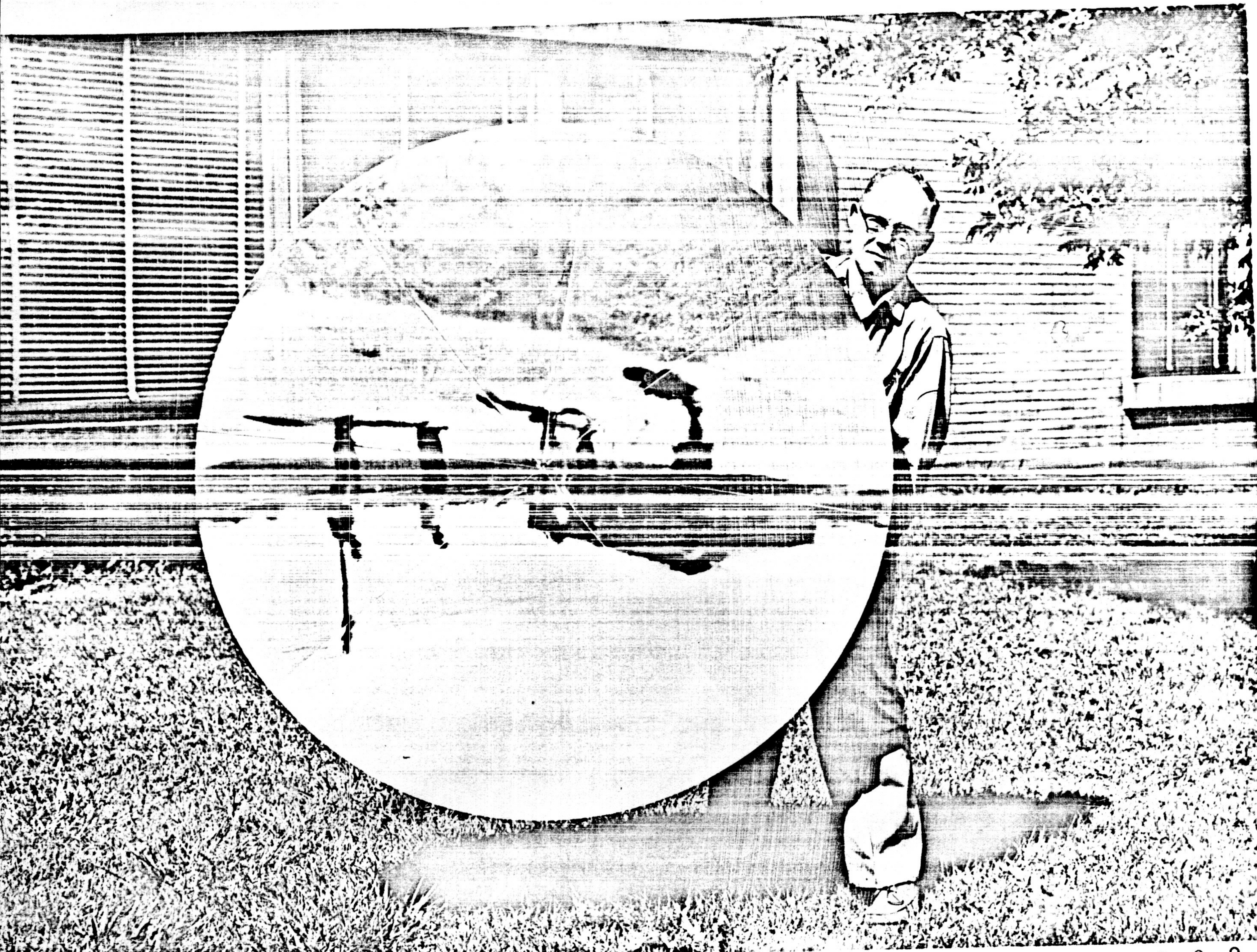


FIG. 3.9 2-A

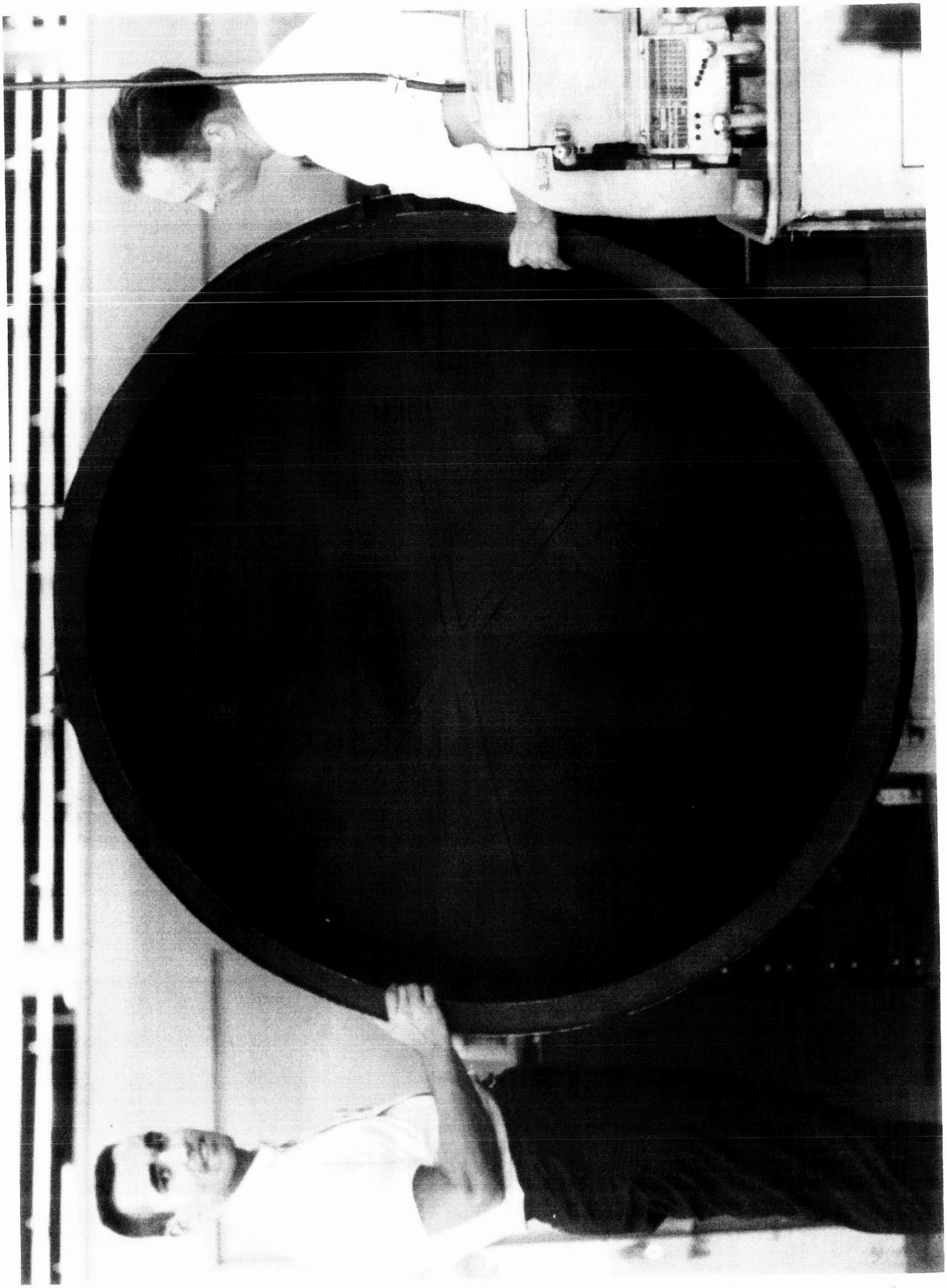


Fig. 1-8

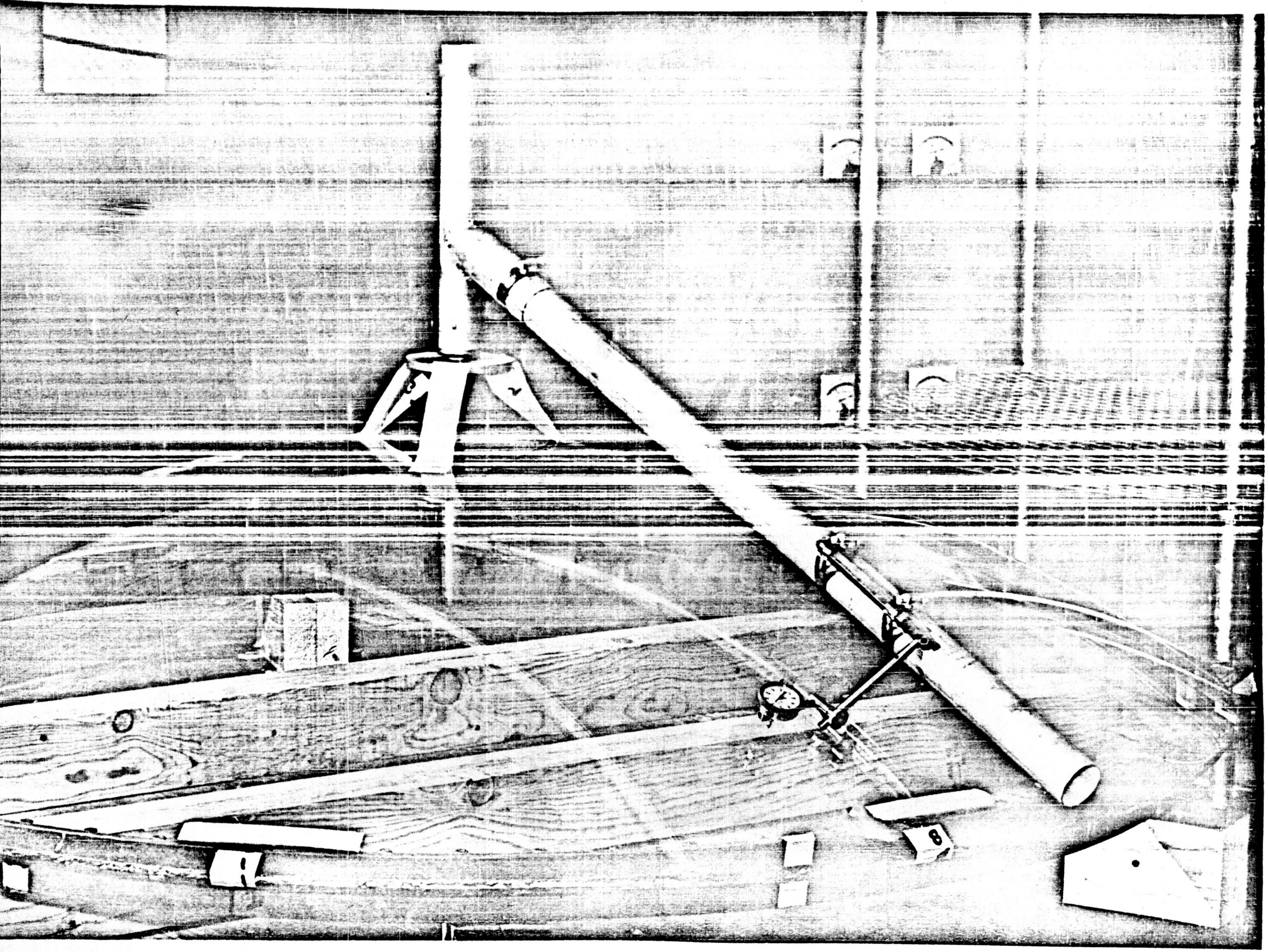


FIG. 3.9.3

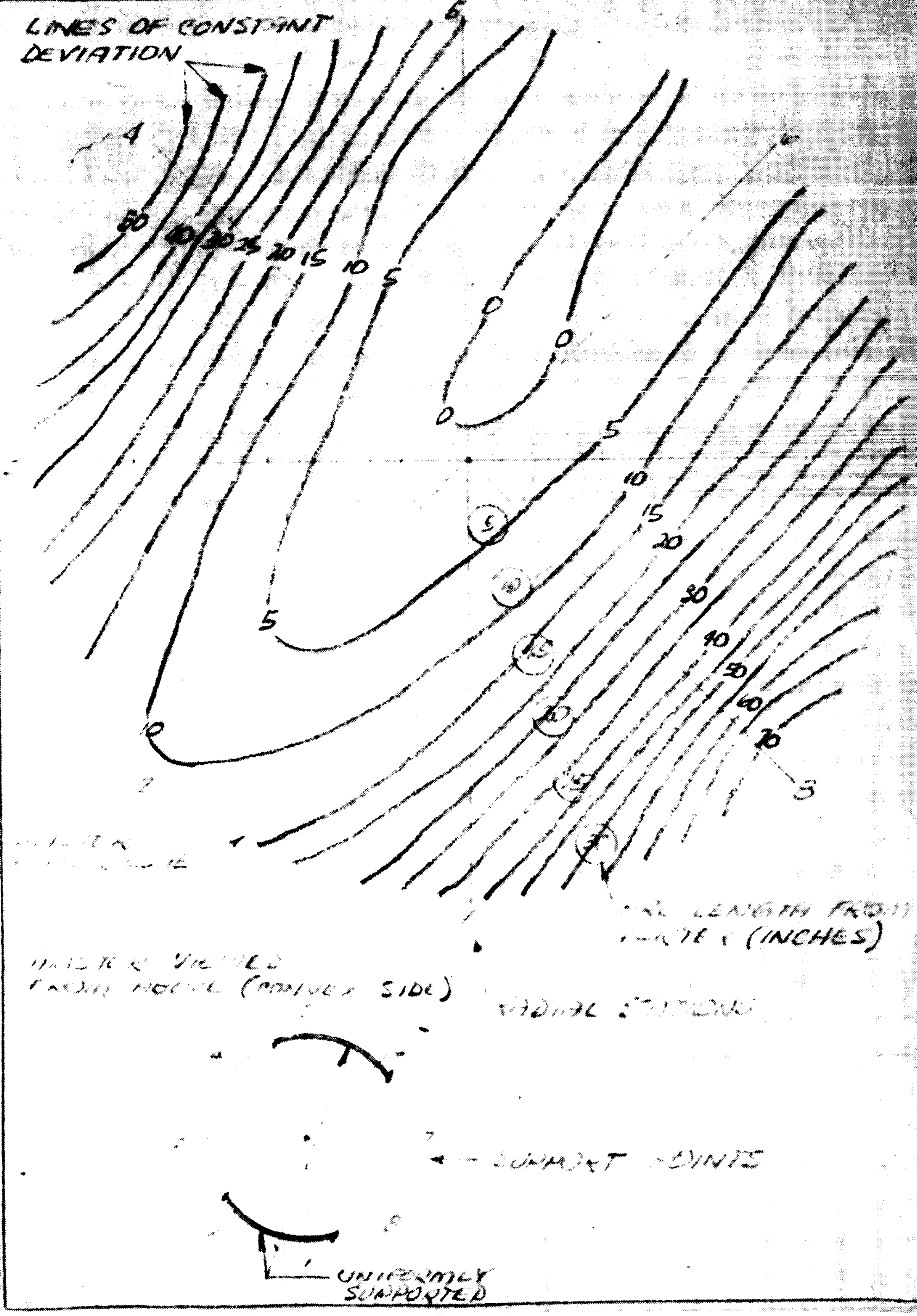
SUBJECT: FIGURE 3.9-4

DIVISION:

PROJECT NO. | PAGE

PREPARED BY: | DATE:

CHECKED BY: | DATE:



PROJECT ANALYSIS SHEET

SUBJECT: FIGURE 3.9-5

DIVISION:

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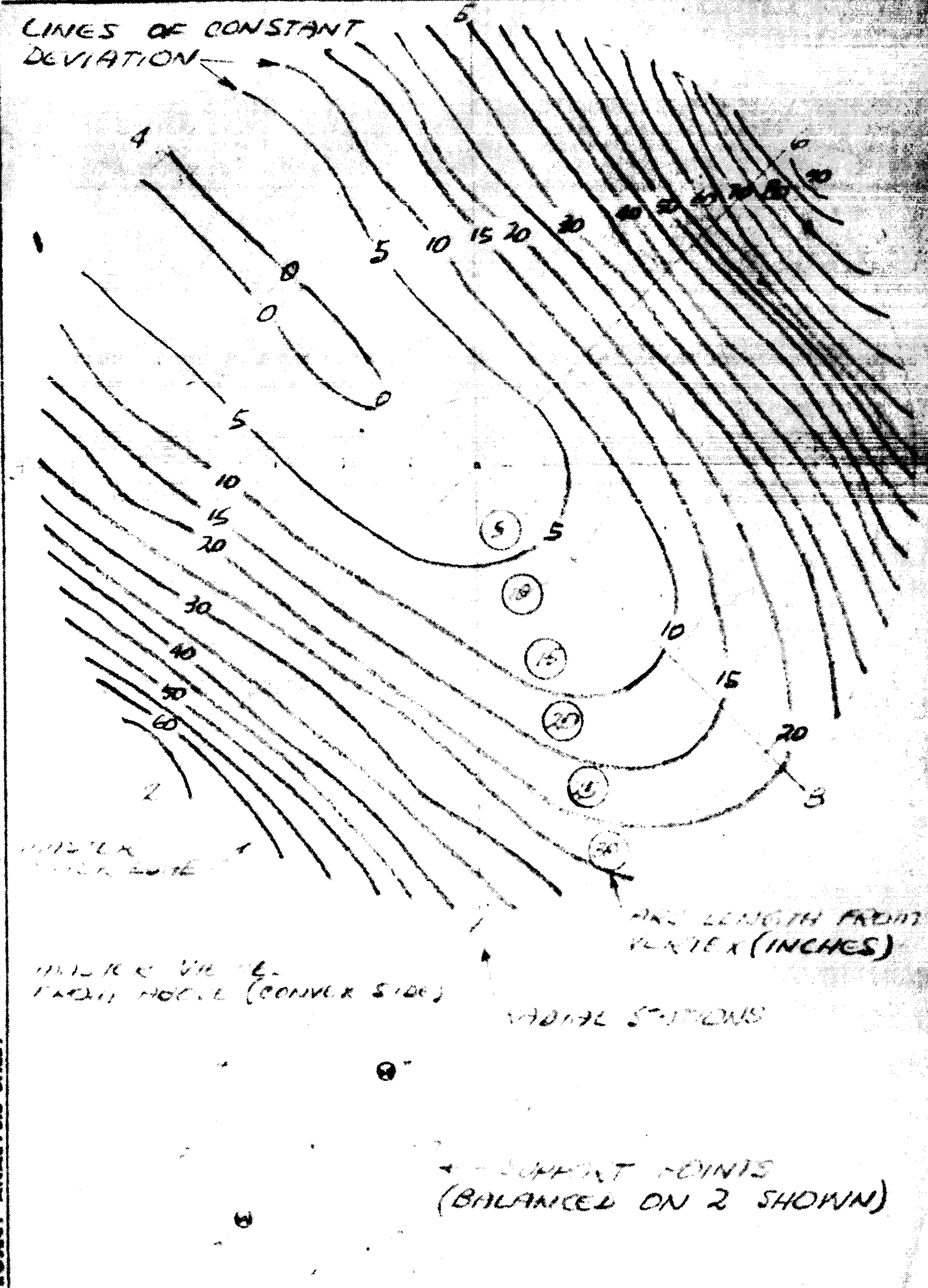

PROJECT ANALYSIS SHEET

SUBJECT

FIGURE 3.9-6

DIVISION

PROJECT NO. PAGE

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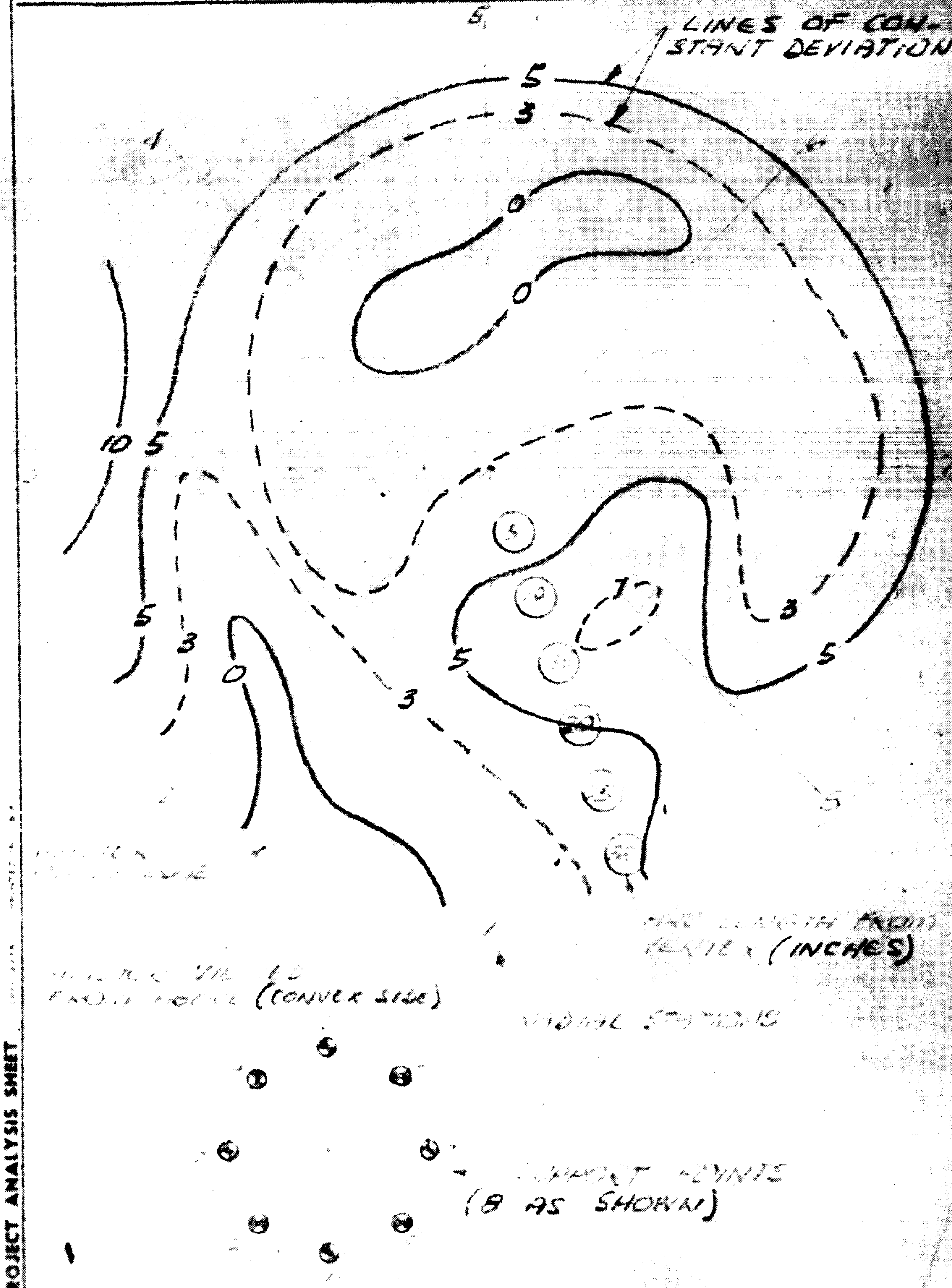

PROJECT ANALYSIS SHEET

SUBJECT:

FIGURE 3.9-4

DIVISION

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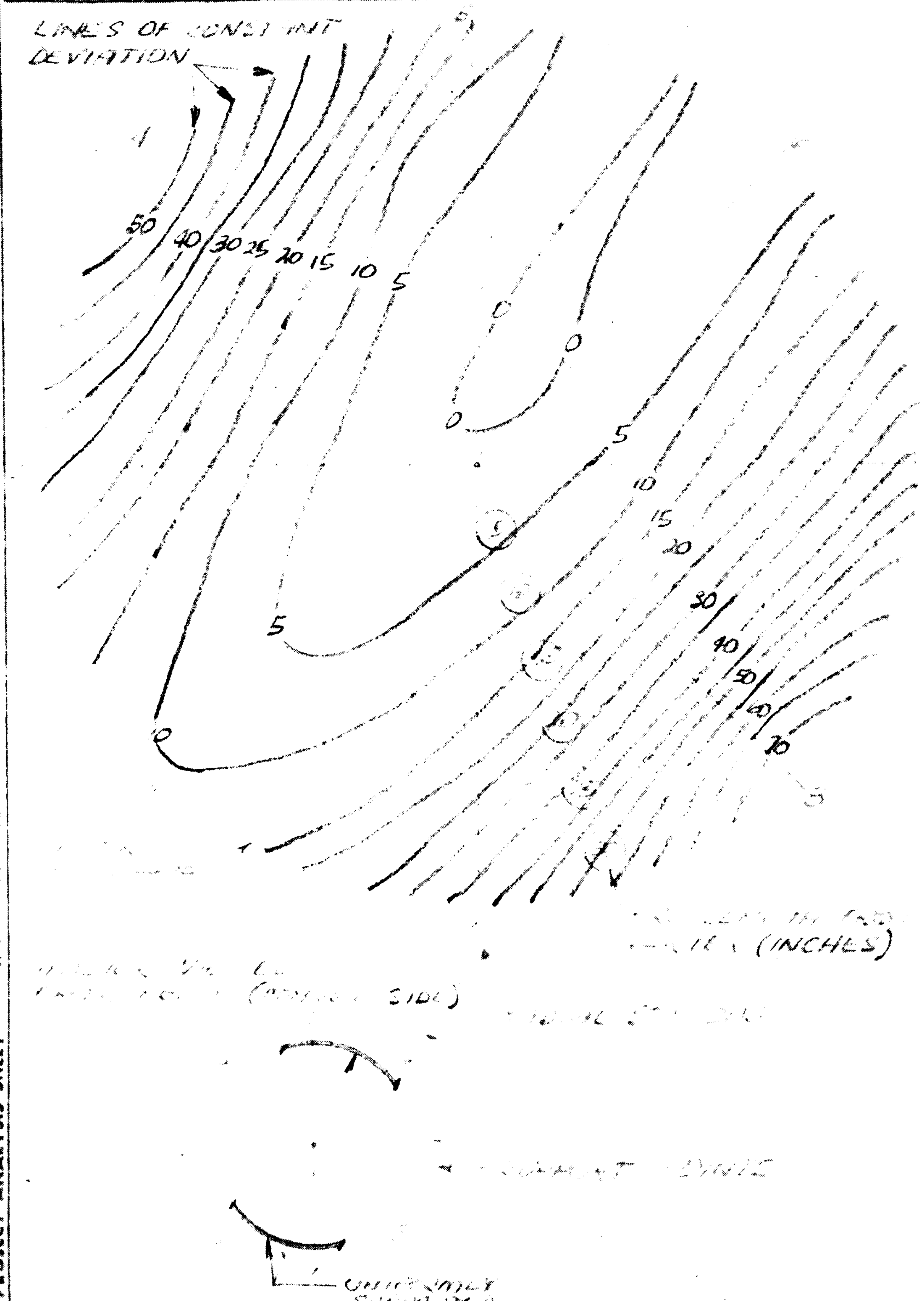
CHECKED BY. DATE.



PROJECT ANALYSIS SHEET

SUBJECT: FIGURE 3.9-5

DIVISION:

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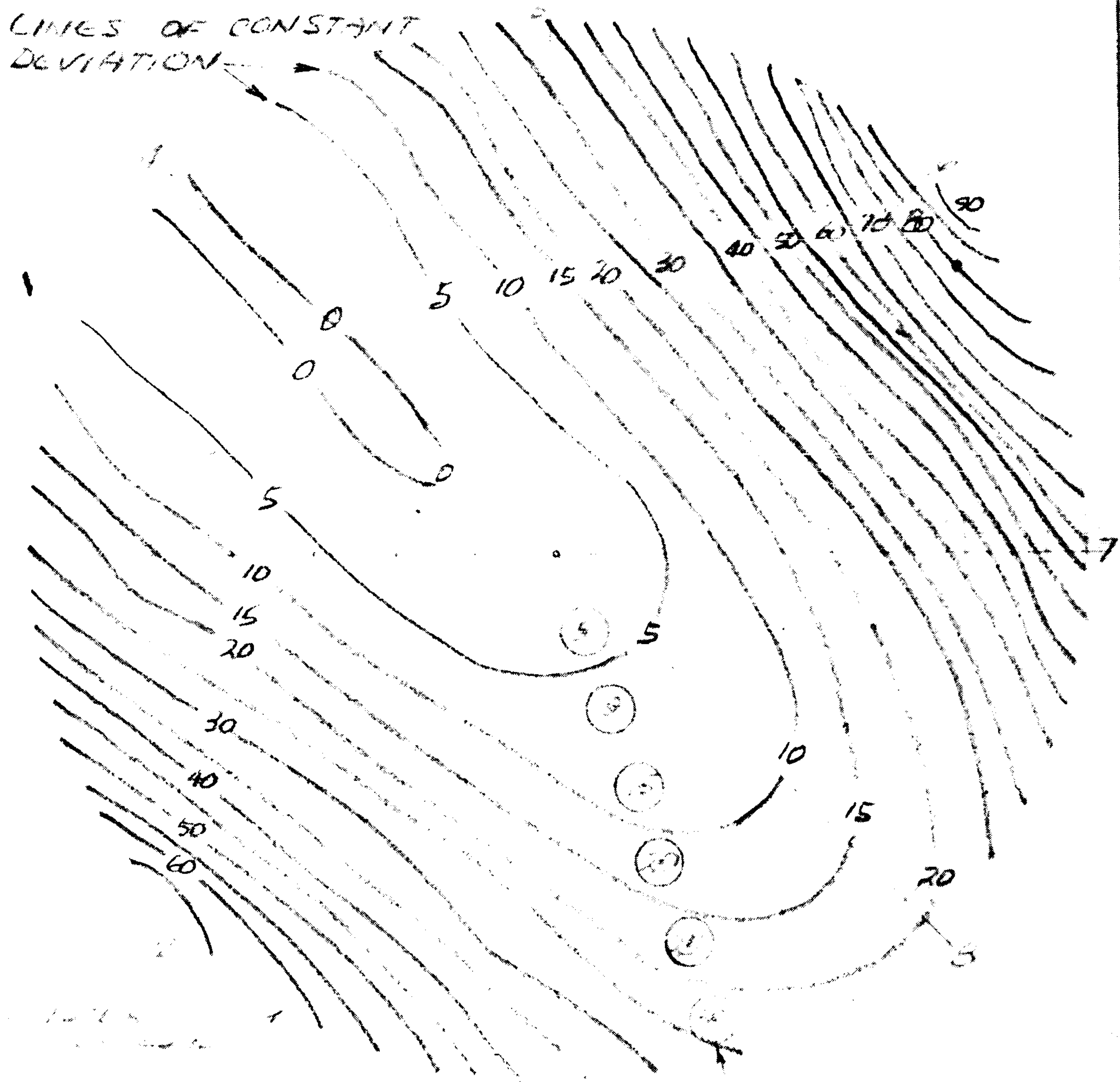

(INCHES)

(BALANCED ON 2 SHOWN)

PROJECT ANALYSIS SHEET

SUBJECT

FIGURE 3.9-6

DIVISION

PROJECT NO | PAGE

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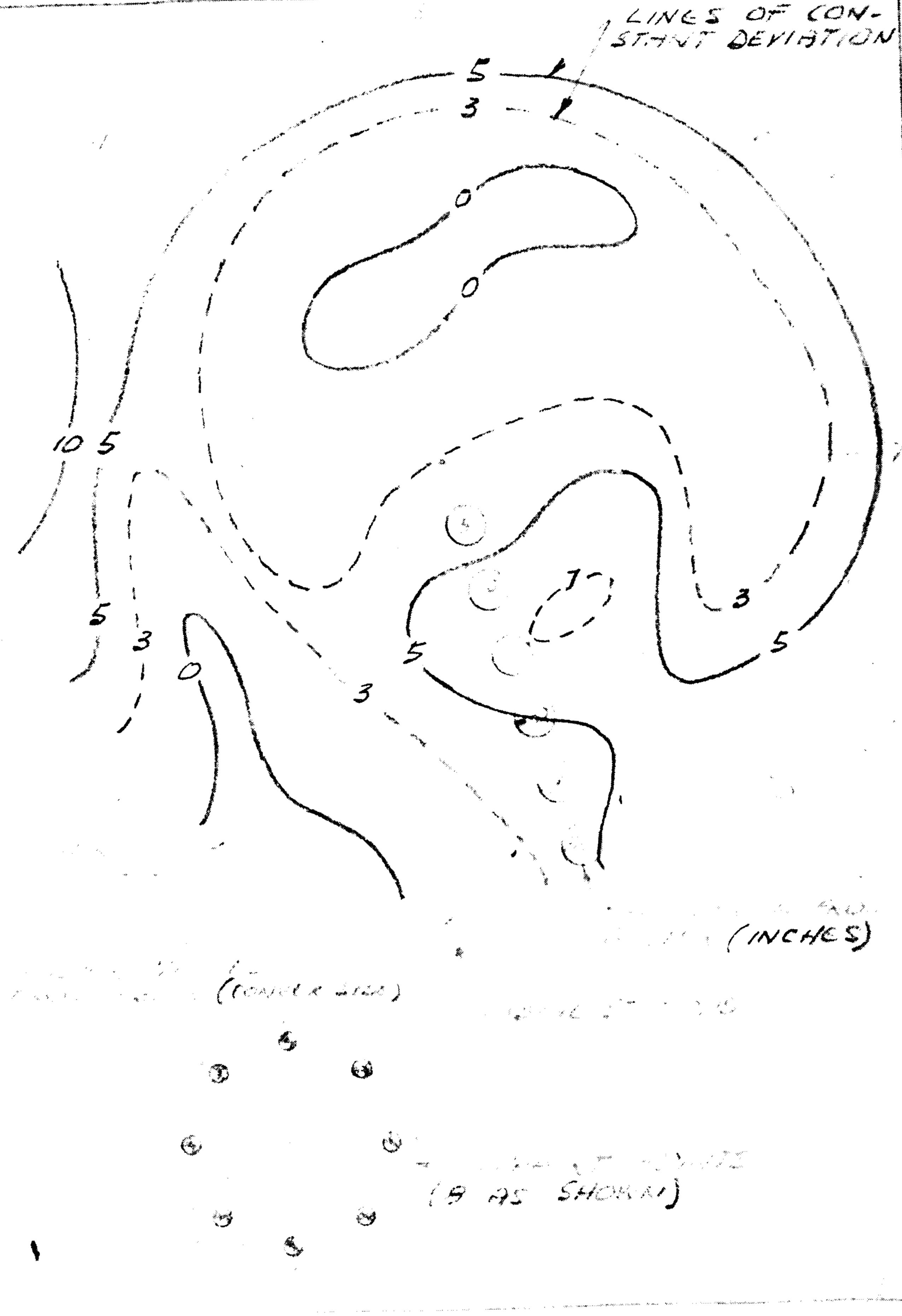

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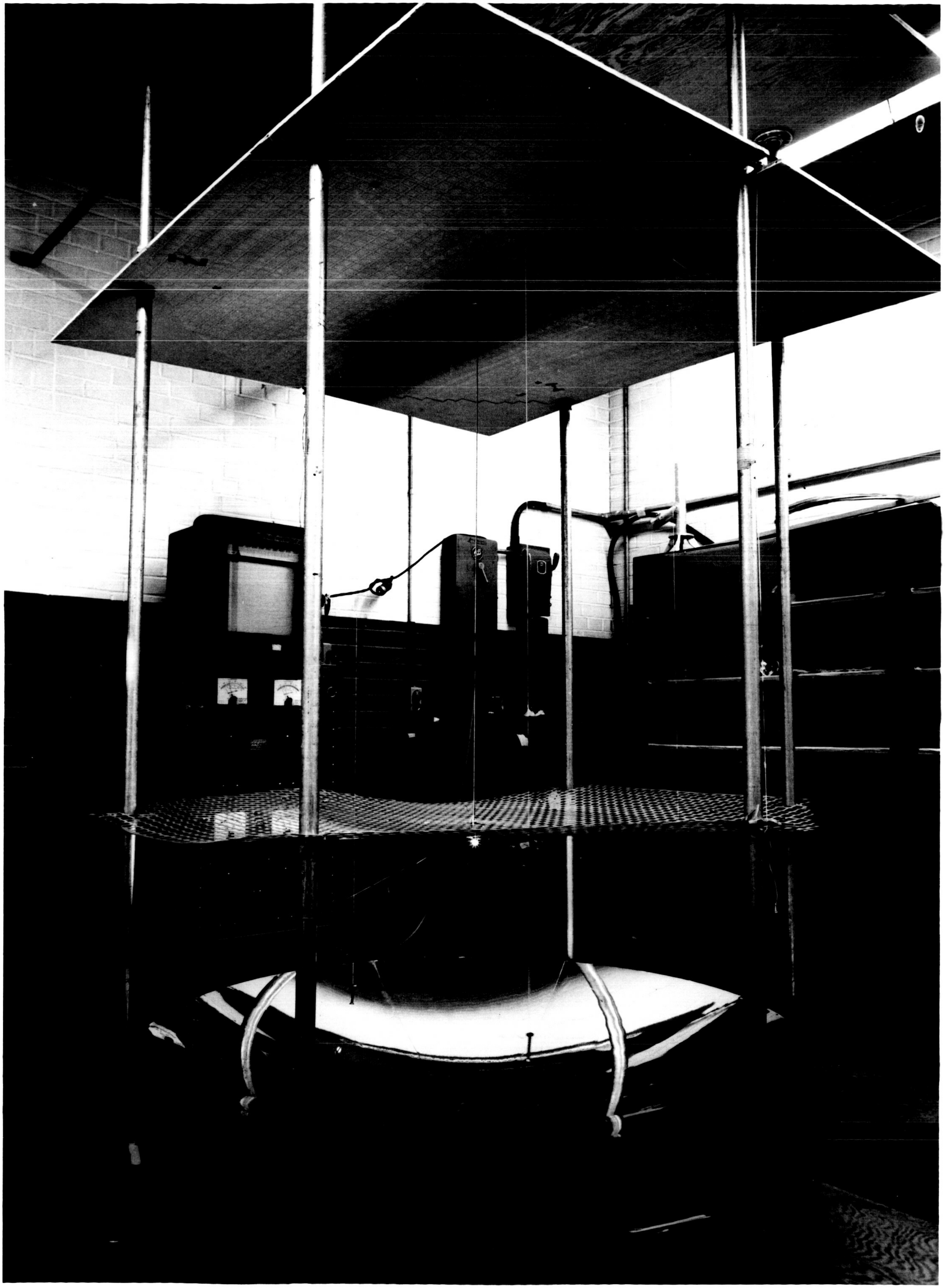


FIG. 3 10 1 [illegible]

NP 8301 205

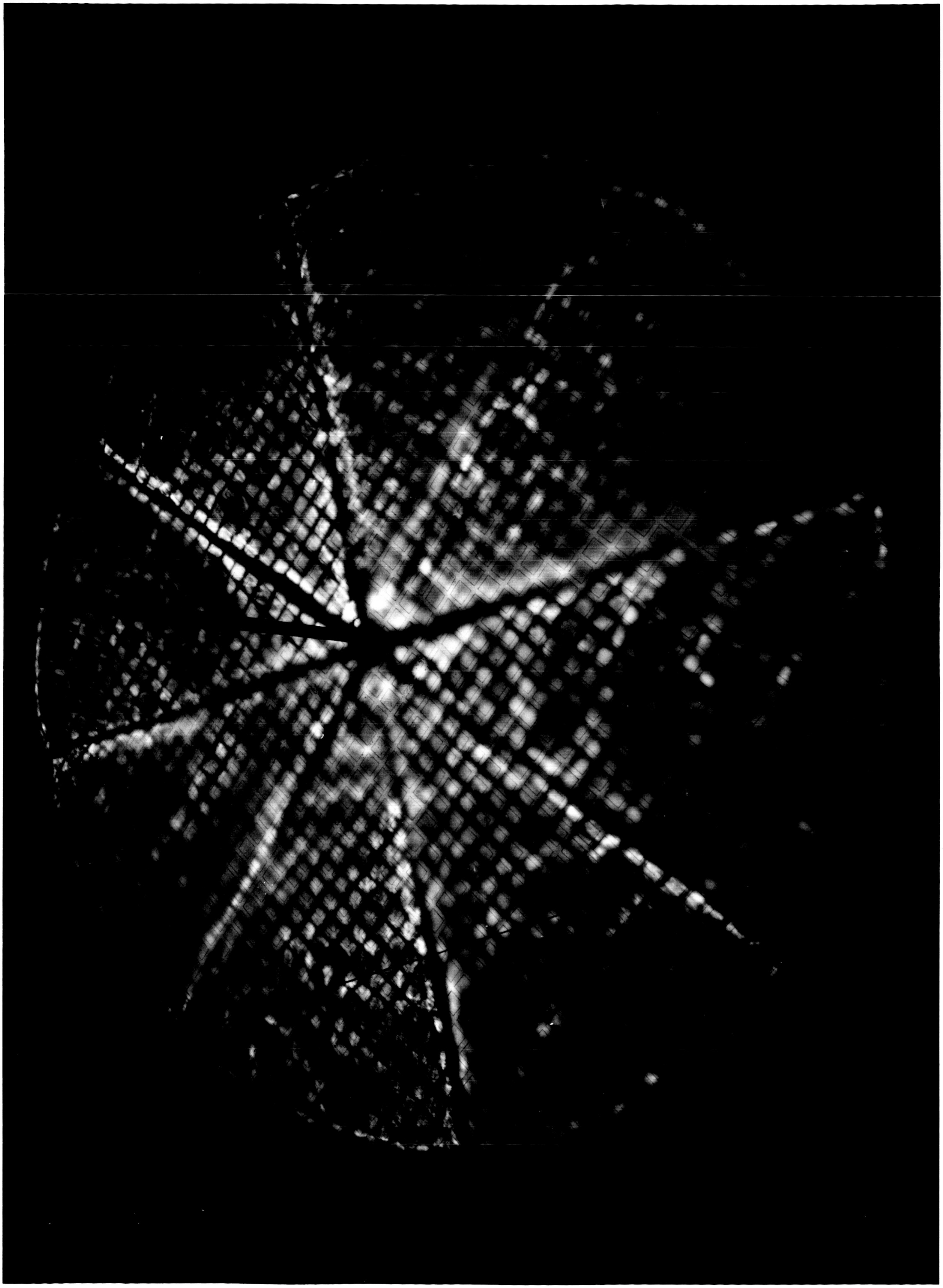


FIG. 3 10 2

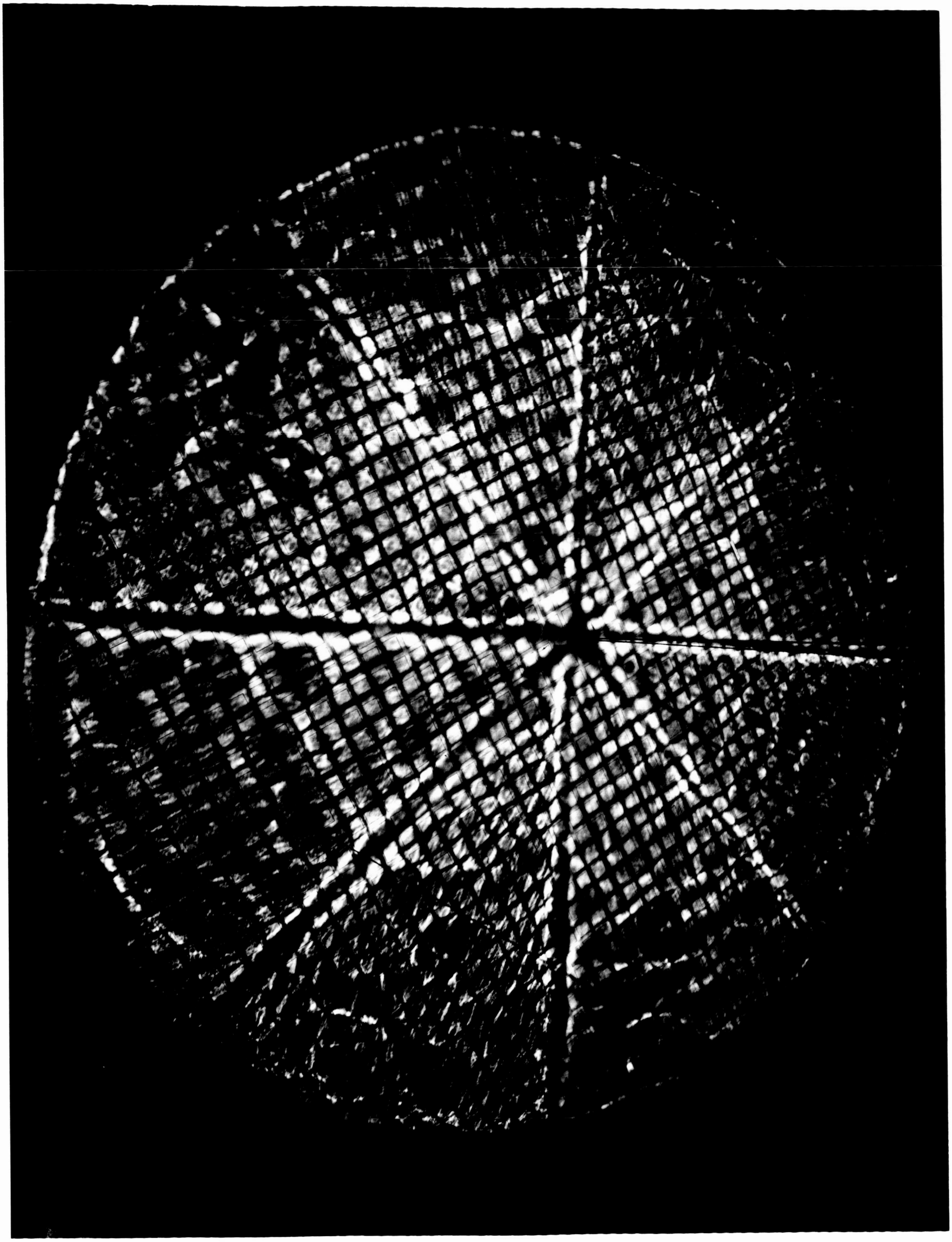


FIG. 3 10 3

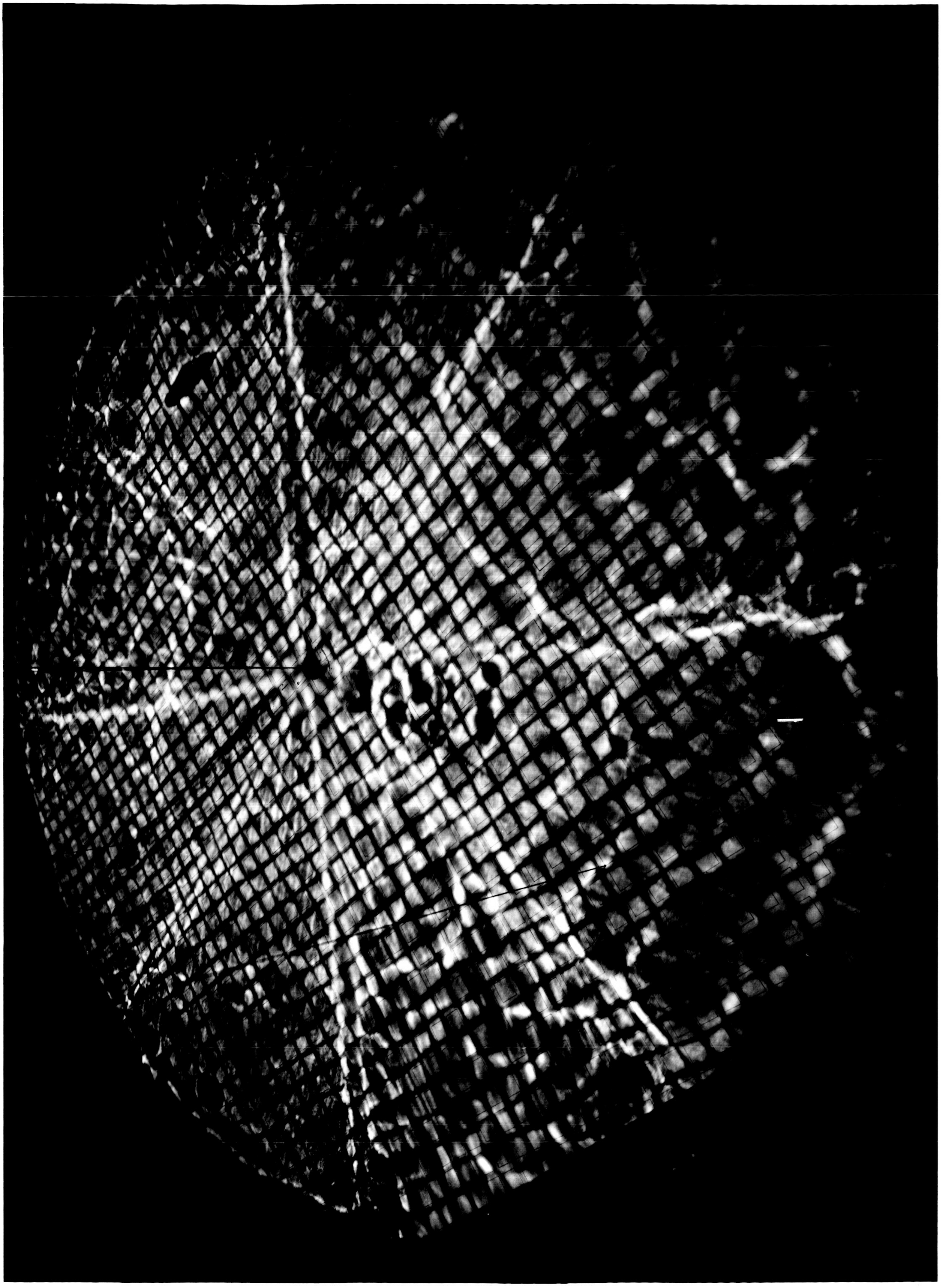
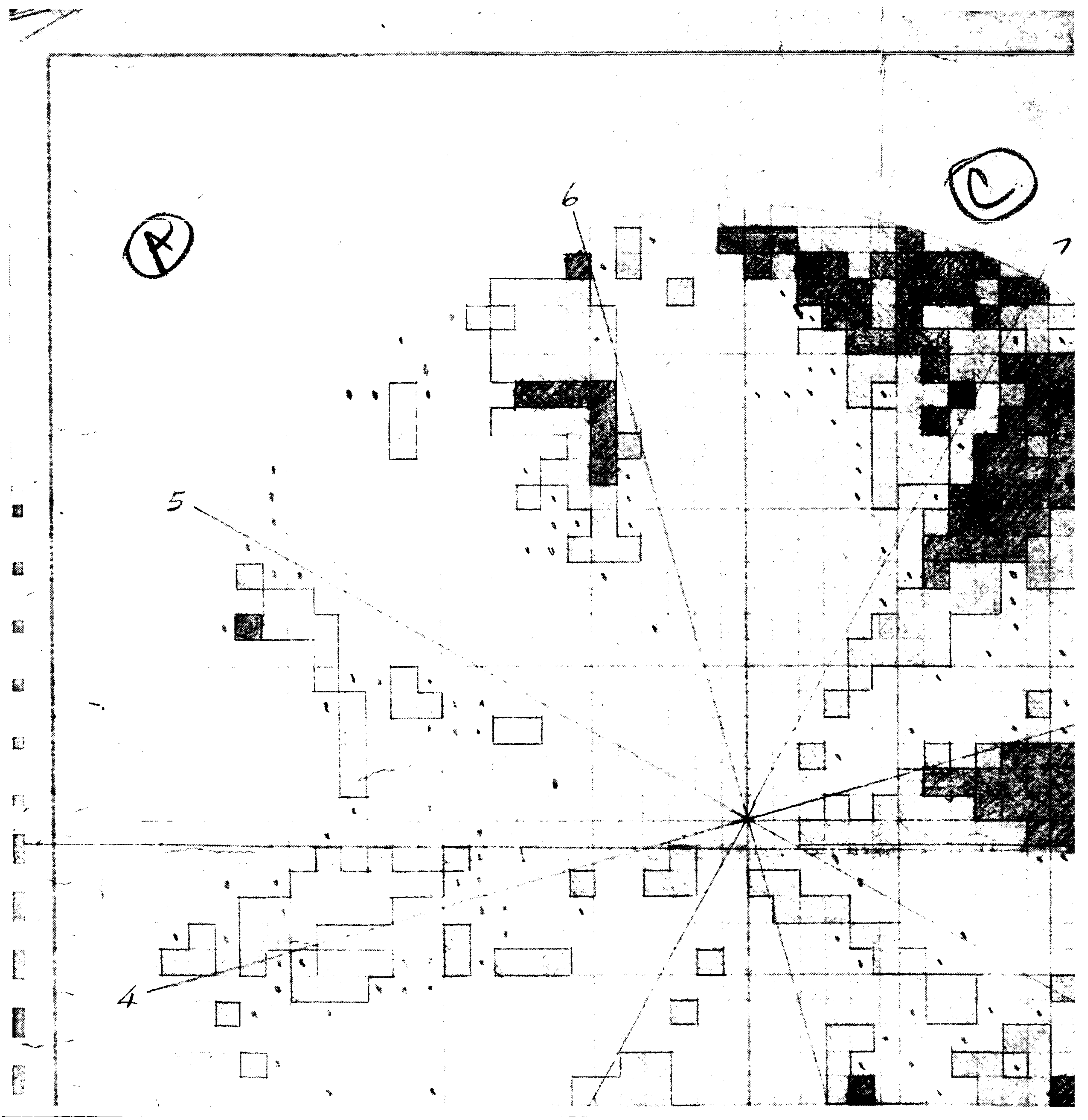


FIG. 3 10 4

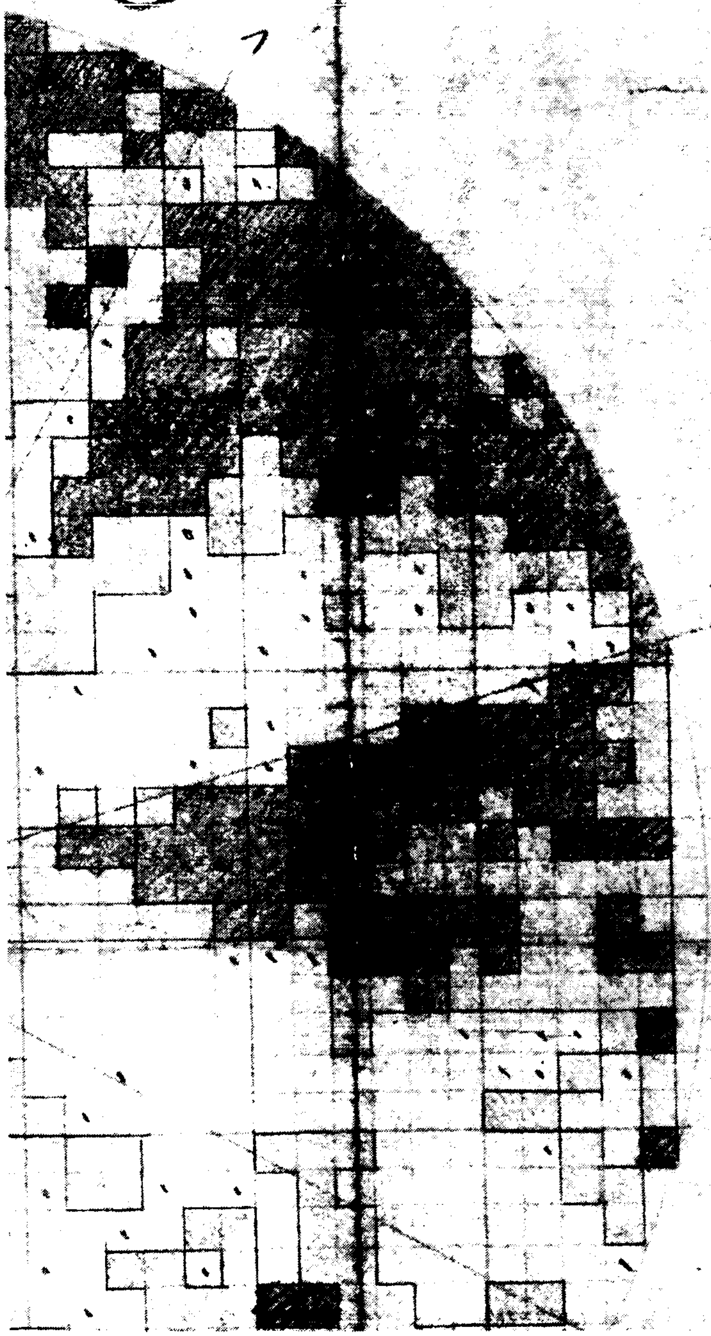

A
C
6
7
5
4

REVISION

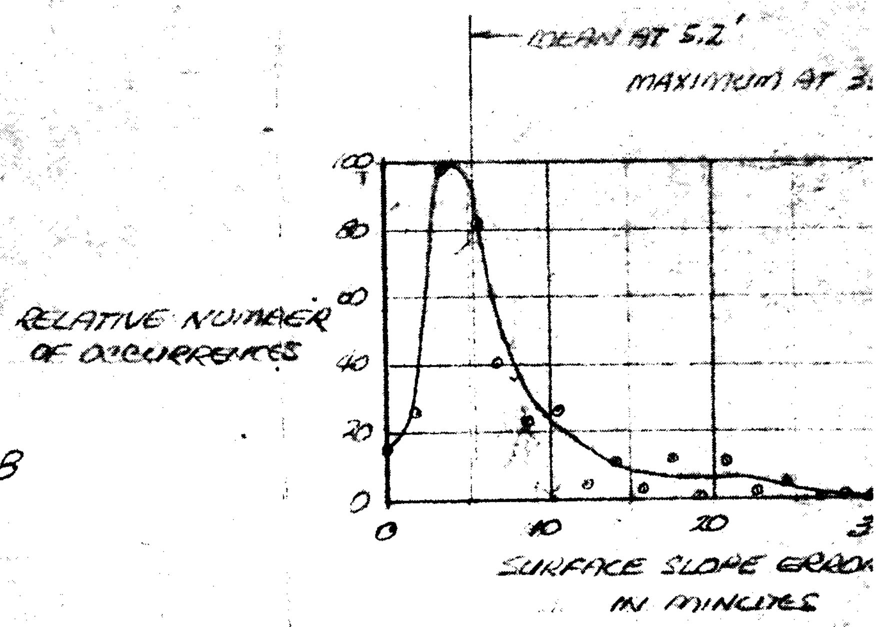
SYM	DESCRIPTION

C

E



DISTRIBUTION CURVE



F

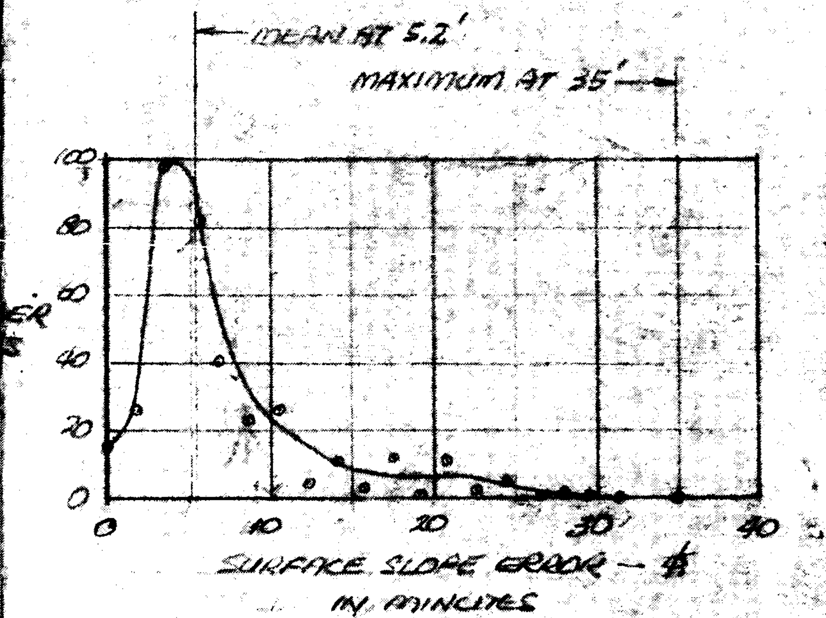
GREATER THAN 17' SLOPE ERROR

REVISIONS

SYM	DESCRIPTION	D.C.N.	DRAWN	CHK'D	DATE

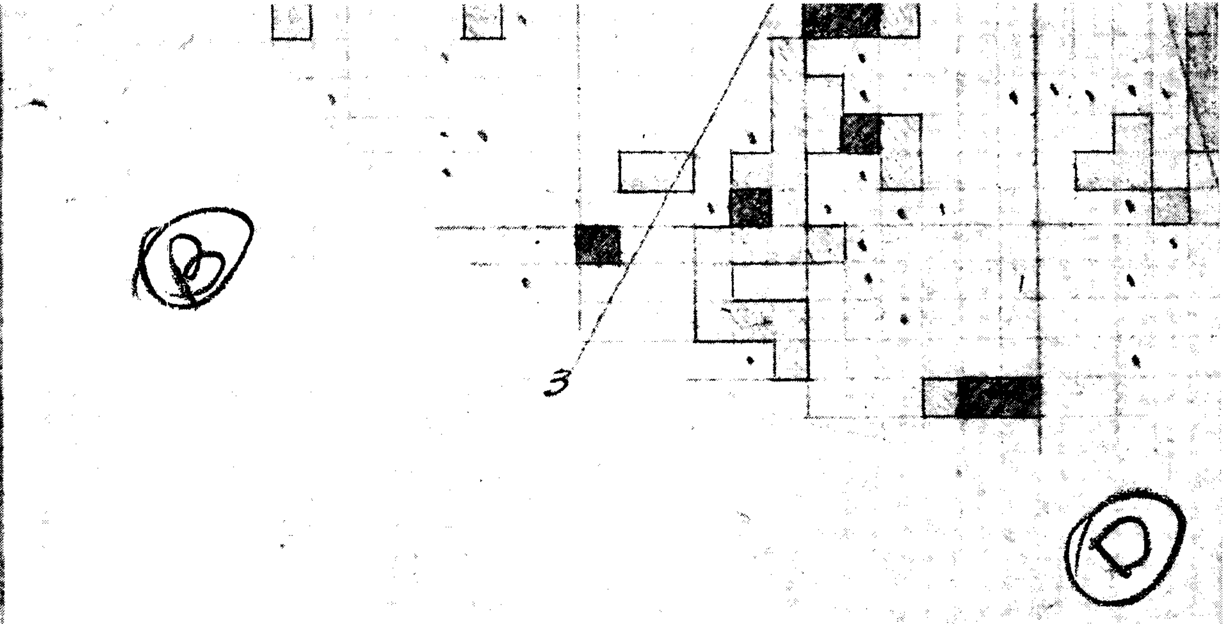
E

DISTRIBUTION CURVE

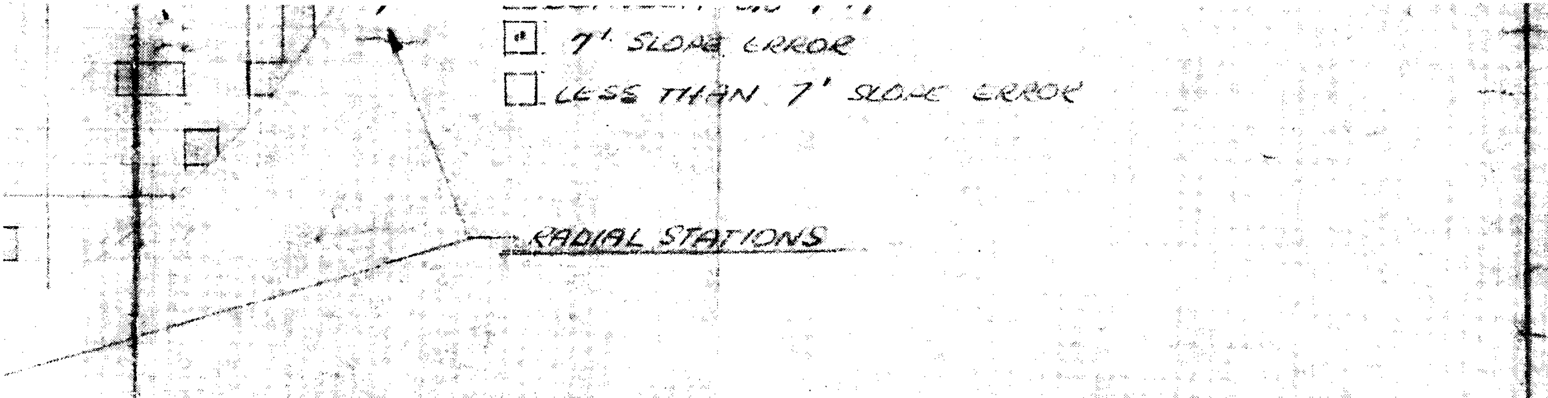


F

HAN 17' SLOPE ERROR



1. COLLECTOR VIEWED FROM CONVEX SIDE (REAR)



ITEM No	REQD.	PART NO.	DESCRIPTION	REF. NO.

LIST OF PARTS

...CIFICATIONS
...SE SPECIFIED
...TOLERANCING IN
...SPEC. MIL STD...

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
REMOVE ALL BURRS
BREAK SHARP EDGES .005/.015
MACH. CORNERS .005/.020 FILLET R.
CAST RAD.

TOLERANCES ON:

DECIMALS	FRACTIONS ±
.X ±.1	ANGLES ±
.XX ± .03	
.XXX ± .010	CORE SHIFT ±

DFTM.
CHKD.
APPD.
ENG. APPD.
ENG. APPD.
MATL. APPD.
MFG.

MATL. & SPEC.
TREATMENT & HARDNESS

TITLE
SURFACE SLOPE ERROR
DISTRIBUTION, S/N 2
1954 LANGLEY 60" COLL.

SCALE | WEIGHT | MFG. CODE

DO NOT SCALE DWG! | DRAWING STATUS

NEXT ASSY. OR REFERENCE NO. | DWG. SIZE C

TAPCO GROUP
THOMPSON RAMO WOOLDRIDGE INC
U. S. A.

DRAWING NO.
FIGURE 3.10-6

CODE 59875 | SHEET

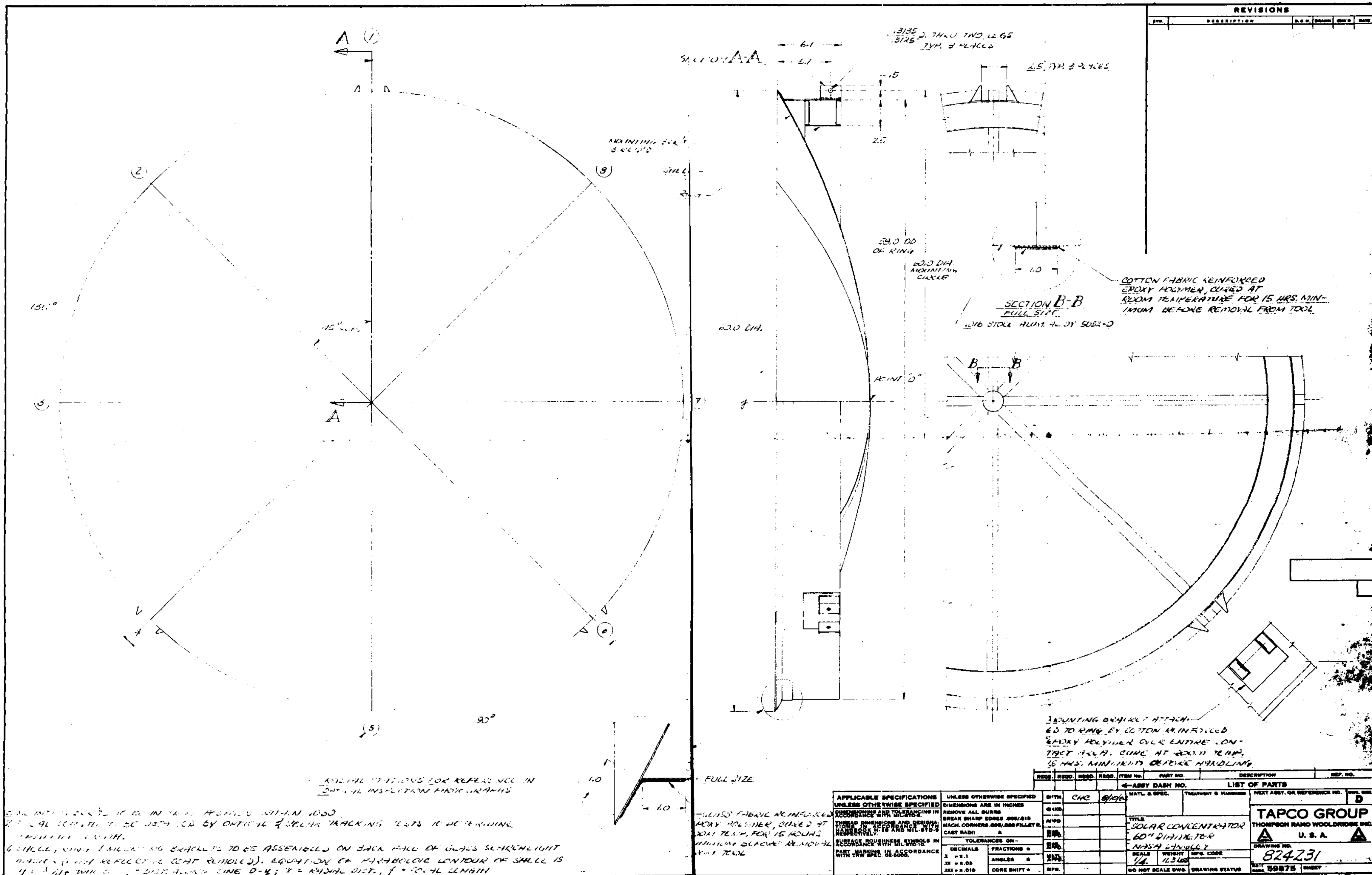

REVISIONS
SECTION A-A
.3135 / .3125 D. THRU TWO LEGS TYP. 3 PLACES
.25 TYP. 3 PLACES
28.0 OD OF RING
60.0 DIA. MOUNTING CIRCLE
60.0 DIA.
POINT "0"
SECTION B-B
FULL SIZE
.016 STOCK ALUM. ALLOY 5052-0
COTTON FABRIC REINFORCED EPOXY POLYMER, CURED AT ROOM TEMPERATURE FOR 15 HRS. MINIMUM BEFORE REMOVAL FROM TOOL
MOUNTING BRACKET ATTACHED TO RING BY COTTON REINFORCED EPOXY POLYMER OVER ENTIRE CONTACT AREA. CURE AT ROOM TEMP. 15 HRS. MINIMUM BEFORE HANDLING
FULL SIZE
RADIAL STATIONS FOR REFERENCE IN OPTICAL INSPECTION PHOTOGRAPHS
90°
45°
135°
APPLICABLE SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
LIST OF PARTS
TAPCO GROUP
THOMPSON RAMO WOOLDRIDGE INC.
U. S. A.
SOLAR CONCENTRATOR
60" DIAMETER
NASA LANGLEY
824231
59875
DO NOT SCALE DWG.
PRODUCT DRAWING TPPC 2221 D

FIGURE 3.3

DISTRIBUTION OF SURFACE SLOPE ERRORS ON INDIVIDUAL SECTORS

DEVIATION ΔX	0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0
NO OCCUR. SECTOR 3-4	11	28	67	61	25	13	5	2	2	1											
NO OCCUR. SECTOR 7-8	1	0	31	37	27	15	17	4	9	0	16	3	16	4	14	0	3	2	2	0	1

SECTOR NO	AVERAGE [illegible]	MEAN [illegible]
3-4	4.6	3.5
7-8	12.8	[illegible]

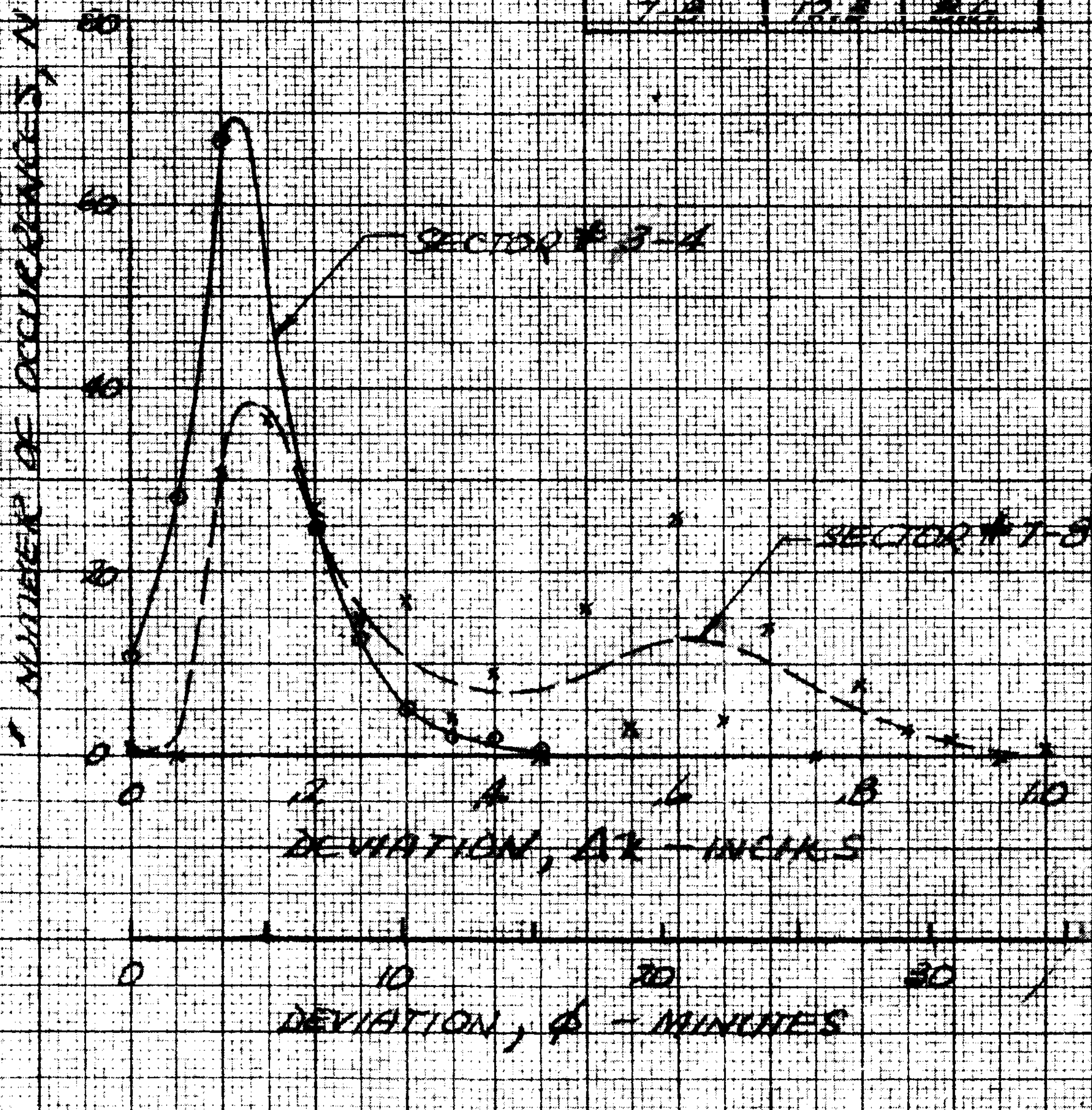


FIGURE 3.10-7

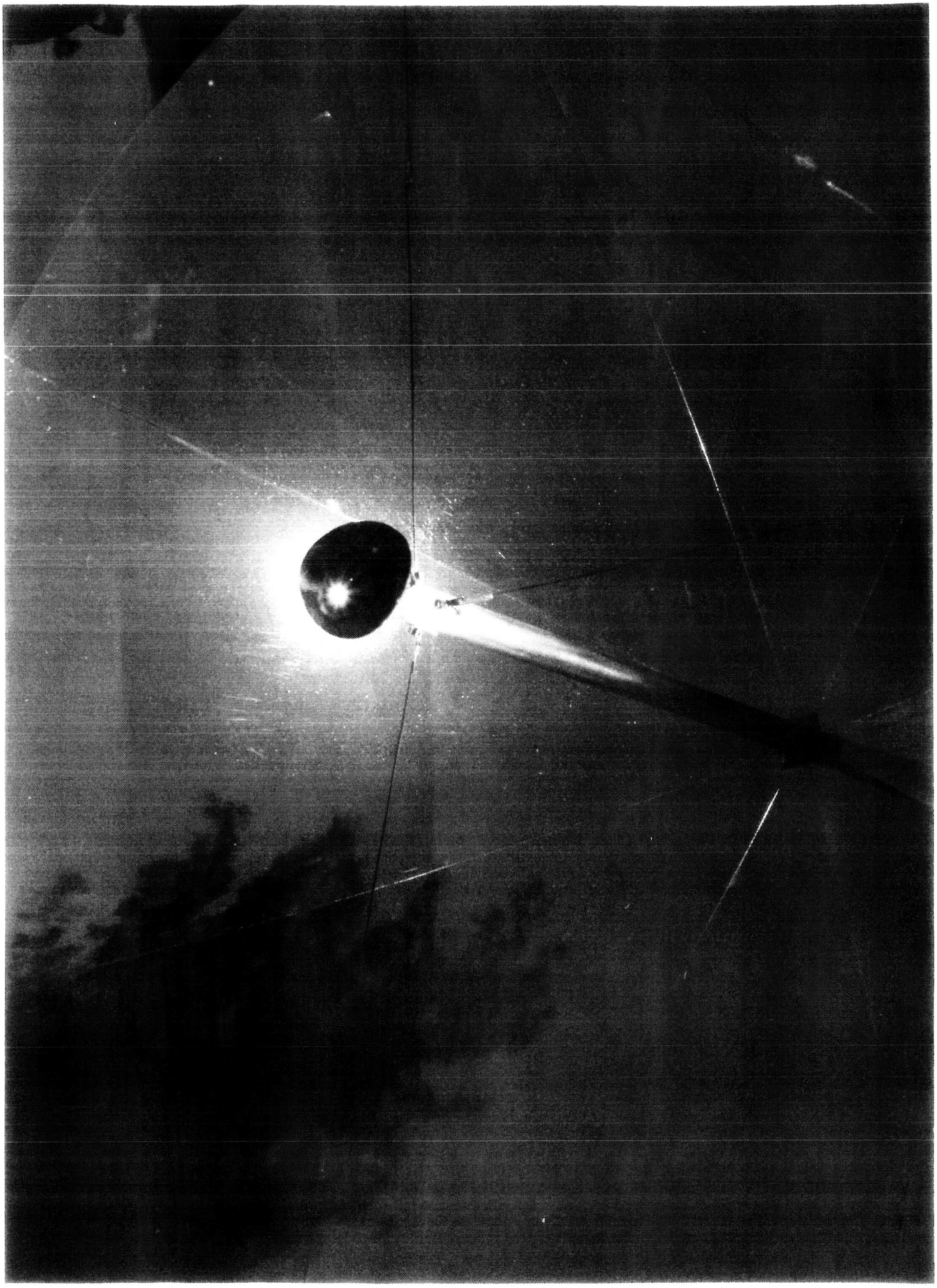


FIG. 3 10 9-A

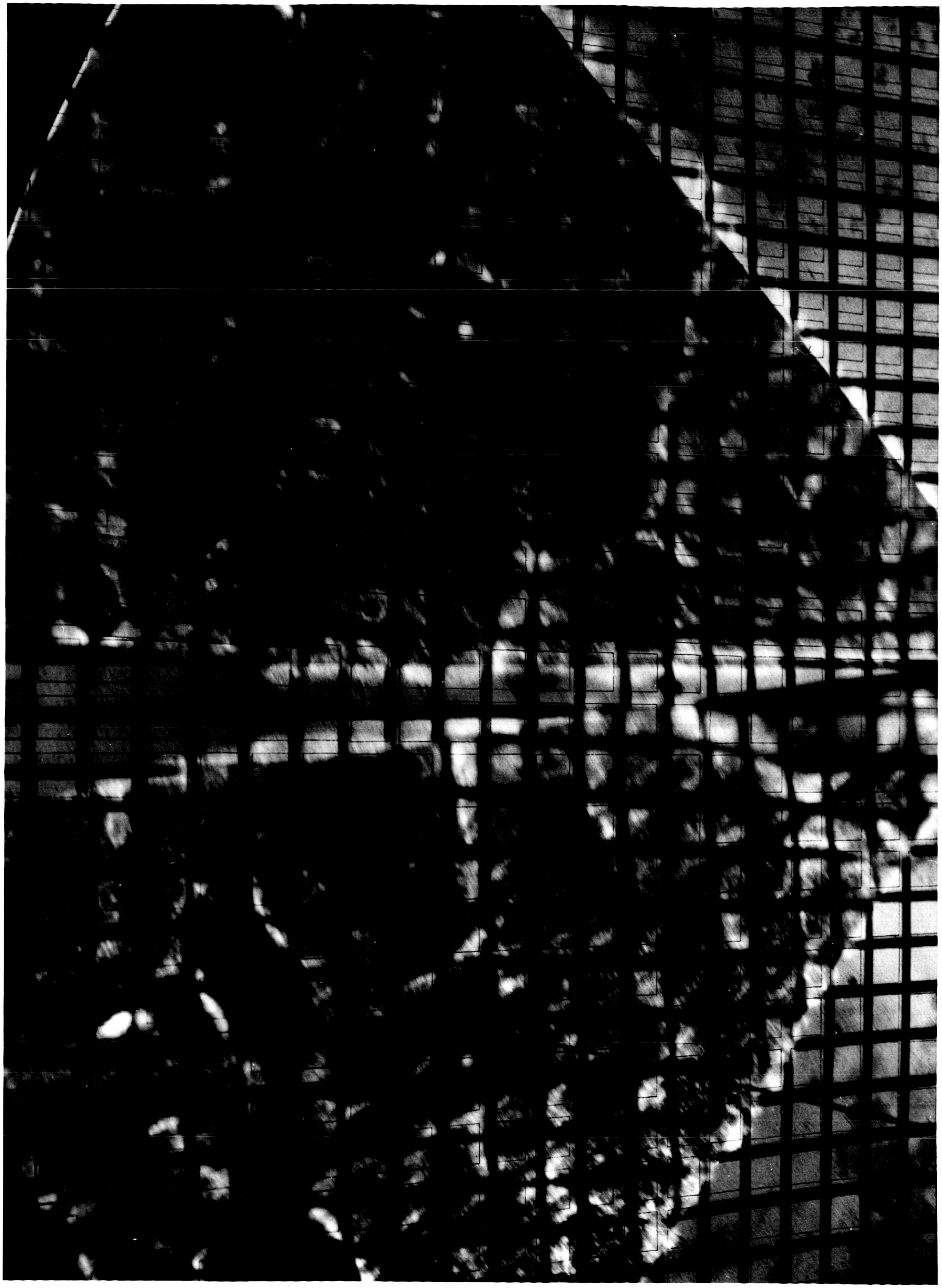


FIG. 3.10 B

FIGURE 3.10-10B

(Next)

ITEM	SERIAL Nº 1	SE
6. PROTECTIVE COAT	WITHOUT BREAKING VACUUM FROM PREVIOUS STEP APPLY SILICON OXIDE AT 7-8 $\times 10^{-4}$ TORR THICKNESS 5800 ANGSTROMS	SILIC 1900
7. REFLECTIVITY - TOTAL HEMISPHERICAL. OBTAINED BY INTEGRATING $R_\lambda I_\lambda$ CURVE WHERE: R_λ = SPECTRAL REFLECTIVITY I_λ = SPECTRAL SOLAR INTENSITY SPECIMEN COATED SAME AS SEGMENTS IN EACH LOT.	SPECIMEN NOT PREPARED	0.8
8. MOUNTINGS	AS SHOWN IN FIG. 3.3-1 EXCEPT RING DIA. IS ~58.4" INSTEAD OF 58.[illegible]" THEREFORE MOUNTING CIRCLE IS ~60.4" INSTEAD OF 60.0"	SAME CIR
9. FOCAL LENGTH - APPARENT. OBTAINED BY ADJUSTING FOCAL LENGTH DURING PROJECTED GRID OPTICAL INSPECTION UNTIL BEST SHADOW TO PATTERN ALIGNMENT OCCURS	26.2" SUBSEQUENT STUDY OF INSTALLATION PHOTOS INDICATE FOCAL LENGTH WAS LESS BECAUSE OF INCORRECT SETTING OF SHADOW & SCREEN	15.6
10. OPTICAL	SEE FIGURE 3.10-2	SEE CO MS WA OB

SERIAL Nº 2	SERIAL Nº 3
SAME AS S/N 1 EXCEPT; 1800 Å	SAME AS S/N 1 EXCEPT; 2200 Å
0.98	0.99
SAME AS S/N 1 EXCEPT MOUNTING CIRCLE [illegible] ~60.1"	SAME AS S/N 2
25.6	25.6"
SEE FIGURE [illegible] 10-3 10-5 10-6 10-7 10-8 CONCENTRATED SPOT WITH MINIMAL [illegible] ING OF SUN [illegible] < [illegible] (VISUAL OBSERVATION	SEE FIGURE 8.10-4

ITEM	SERIAL Nº 1
1. WEIGHT ⊙ CALCULATED * MEASURED	SHELL —— 5.12 LBS ⊙ BRACKETS —— 0.34 * RING —— 4.44 * ADHESIVE —— 1.35 ⊙ TOTAL —— 11.25 *
TOTAL WEIGHT DIVIDED BY INTERCEPTED COLLECTOR AREA →	SPECIFIC —— 0.58 LB/FT.²
2. MATERIALS	SECTORS — ALUMINUM ALLOY 5052-0, .016" THICK, SURFACE FINISH ON REFLECTIVE SIDE < 2 μ" RMS RING — ALUMINUM ALLOY 6061 ½ HARD, .015" STOCK BRACKETS — ALUMIN. ALLOY 6061-T6 .063" THICK STOCK
3. ADHESIVES & CURE CYCLES	SHELL — BONDMASTER M777 (EPOXY) EQUAL PARTS A & B. REINFORCED WITH 2 LAYERS COTTON CLOTH TOTAL CURE TIME UNDER VACUUM BAGGING OF 42 HRS. RING — ERL 2774 (100 PARTS) AND CURING AGENT "U" (25 PARTS) VACUUM BAGGED 12 HRS. AT ROOM TEMPERATURE. GLASS FIBRE REIN. BRACKETS — BONDMASTER M688 (100 PARTS) WITH CURING AGENT "CH" (34 PARTS) R.T. CURE WITH 15 HRS. VACUUM BAG.
4. SURFACE FINISH METHOD	CLEANING PROCEDURE WIPED WITH TOLUOL/ACETONE SOLVENT CLEANED WITH PEP CO. FORMULA 2961 CLEANER & DEGREASER COLD WATER RINSE CLEANED WITH AEROSOL OT 2% SOL. HOT WATER RINSE & WIPED DRY WITH KIMWIPES IN CLEAN ROOM COAT APPLICATION SPRAYED WITH PEP CO. "VELAC"

	1 HR AIR DRY AT ROOM TEMP. 1 HR AIR CURE AT 180°F.
5. REFLECTIVE COAT	PRE-TREATMENT HANDLED WITH NYLON GLOVES & PLACED IN VACUUM EVAPORATOR FIXTURE SURFACE CLEANED BY GLOW DIS-CHARGE AT $2-5 \times 10^{-2}$ TORR PRESS. SILICON OXIDE UNDERCOAT APPLIED AT $7-8 \times 10^{-4}$ TORR. THICKNESS 2300 ÅNGSTROMS OBTAINED FROM REFLECTED COLOR CALIBRATION CHART REFLECTIVE COAT WITHOUT BREAKING VACUUM, APPLIED 99.99 % PURE ALUMINUM AT $2-3 \times 10^{-5}$ TORR PRES-SURE FOR SECONDS. THICKNESS ~600 ÅNGSTROMS BASED ON PREVIOUS CALIB-RATIONS

B

C

E

SERIAL Nº 2	SERIAL Nº 3
TOTAL ———— 11.31 LBS*	TOTAL ———— 11.12 LBS*
SPECIFIC ———— 0.58 LB/FT.²	SPECIFIC ———— 0.57 LB/FT.²
SAME AS S/N 1 EXCEPT	SAME AS S/N 2.
BRACKETS — ALUM. ALLOY 6061-0	
SHELL — BONDMASTER M777 (EPOXY) EQUAL PARTS A & B; REINFORCED WITH 2 LAYERS COTTON CLOTH TOTAL CURE TIME UNDER VACUUM BAGGING OF 82 HOURS RING — BONDMASTER M666 (EPOXY) EQUAL PARTS A & B, VACUUM BAGGED FOR 16 HOURS WITH GLASS FIBRE FABRIC REINFORCEMENT. BRACKETS — SAME AS RING ALL CURED AT ROOM TEMP.	SHELL — SAME AS S/N 2 EXCEPT REINFORCED WITH 1 LAYER OF GLASS FIBRE FABRIC & CURE TIME OF 64 HRS. RING — ERL 2774 (100 PARTS) AND CURING AGENT "U" (15 PARTS). VACUUM BAGGED 15 HRS. WITH GLASS FIBRE FABRIC REIN. BRACKETS — SAME AS RING EXCEPT 18 HRS. CURE TIME
CLEANING PROCEDURE SAME AS S/N 1 EXCEPT NO ZEP 2861 CLEANING OR COLD WATER RINSE	CLEANING PROCEDURE TOLUOL, ACETONE WIPE WIPED WITH AEROSOL OT (2% SOL) HOT WATER RINSE "KIMWIPE" DRY
COAT APPLICATION SEE CHEMICAL CO. EPOXY COAT 1 PART VOL. "LOGO" CLEAR DSH-20,004 1 " " LOGO CATALYST ET 535 2 " " THINNER 2535	COAT APPLICATION 1 PART EPOXY (LOGO) 1 " CATALYST " 2 " THINNER " 1 " MEK

F

APPLIED IN CLEAN ROOM 1 HR AIR DRY ROOM TEMP 1 HR AIR CURE AT 160°F 32 HRS AIR DRY ROOM TEMP 1 HR AIR CURE AT 160°F	40 HR AIR DRY 1 HR AIR CURE AT 175°F
PRE-TREATMENT SAME AS S/N 1 EXCEPT; GLOW DISCHARGE; 1-4×10^{-2} TORR SILICON OXIDE; 2200 Å THICK,	PRE-TREATMENT SAME AS S/N 1 EXCEPT; GLOW DISCHARGE; 4×10^{-2} TORR SILICON OXIDE; 3000 Å THICK
REFLECTIVE COAT SAME AS S/N 1 D	REFLECTIVE COAT SAME AS S/N 1

FIGURE 3.10-10A